State of California
THE RESOURCES AGENCY
Department of Water Resources
BULLETIN NO. 136

NORTH COASTAL AREA INVESTIGATION

Appendix E
ENGINEERING GEOLOGY

Volume II: Trinity River, Lower Eel River, and Klamath River Developments

AUGUST 1965

HUGO FISHER
Administrator
The Resources Agency

EDMUND G. BROWN
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WILLIAM E. WARNE
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Volume 11: Trinity River, Lower Eel River, and Klamath River Developments

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FOREWORD

Appendix E is divided into two volumes. Volume I discusses the engineering investigations and general engineering geology features in the North Coastal area and covers the possible Upper Eel River Development projects, including the Middle Fork Eel River projects, the Glenn Reservoir projects, and the upper Eel River projects. This volume, containing Chapters V to X, covers other possible projects in the North Coastal area within the Trinity, South Fork Trinity, Mad, Van Duzen, lower Eel, and Klamath River drainage areas. The Greater Berryessa Project is also covered. The information presented in this volume will provide a basis for further investigation of projects which will follow the Upper Eel River Development.

The coverage devoted to individual damsites and tunnel alignments varies with the level of work performed and the importance of the feature in the plans for development. Discussions of major damsites include detailed descriptions of the foundation conditions and descriptions of anticipated problem areas. In addition to these detailed reports, geologic conditions of alternative features of the investigation are presented in tabular form.

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CHAPTER V. TRINITY RIVER PROJECTS

The engineering geology of project features investigated for diversion of the Trinity River as the first stage of the Trinity River Development is presented in this Chapter. Featured projects which are discussed in detail and shown on Platè 1 include Helena and Burnt Ranch Dams, Cottonwood Tunnel, Clear Creek Tunnel No. 2, and the West Side Conveyance System. Geologic maps, cross sections, and maps showing the locations of construction materials for these projects appear at the end of this volume as Plates 22 to 31.

Also presented is geology of damsites considered as alternatives and other featured projects shown on Plate 1 which have not been as thoroughly investigated. Geologic data on these sites are presented in brief reports or in tabular form, but no maps are included. Big Bar damsite, an alternative to Helena damsite, is reported on in some detail while data on other sites including Beaver, Hoopa, Horse Linto, and Ironsides on the Trinity River, Beartooth on New River, and Seltzer, Girvan, Towerhouse, and Kanaka on Clear Creek are presented in Table 17. Brief geologic data on one other tunnel route, New River Tunnel, are presented in Table 18.

Helena Damsite

Helena damsite is located in Trinity County on the Trinity River, approximately 12 miles west of Weaverville. The axis lies mostly within the SE$\frac{1}{4}$ of Section 36, T34N, R12W, MDB&M.

The site is accessible by U. S. Highway 299 which crosses the lower portion of the right abutment. The old highway, parts of which are still serviceable, is 270 feet above Highway 299. During the exploration program, the old highway was used between Big Flat campground, 2$\frac{1}{2}$ miles downstream from the axis, and the damsite. The left abutment may be reached on foot from a bridge which crosses the Trinity River about 5 miles downstream from the axis.

Topography of the area is shown on the 15-minute Hayfork and Helena quadrangles, both published in 1951 by the U. S. Geological Survey at a scale of 1:62,500 and a contour interval of 50 feet. The boundary between these two quadrangles bisects the dam axis. Also published by the USGS is a detailed topographic map of Helena damsite at a scale of

1 inch = 200 feet and a contour interval of 10 feet, but the map extends only up to an elevation of 1,800 feet. Above that, and also extending in an upstream direction a short distance, the Department of Water Resources has added contours with 50-foot intervals.

Description of Project

At the time of exploration, a 575-foot-high concrete gravity dam with an overflow spillway was planned at the site. A diversion tunnel about 1,600 feet long was proposed beneath the right abutment. Present plans are for a rockfill dam approximately 600 feet high, which would increase the required length of the diversion tunnel.

Geology of the Site

The topography is very rugged in the general vicinity of the damsite, with elevations rising from about 1,300 feet at the streambed to more than 3,500 feet slightly less than 1 mile south of the site. The gradient of the Trinity River at the damsite is about 40 feet per mile.

Vegetation is moderate on the right abutment and consists mostly of trees and light brush. The rock is somewhat better exposed on this side due to the roadcuts and also to the lighter amount of vegetation. The channel area is clear. A thick cover of trees and brush is present on the left abutment. Talus covers a large part of the left abutment and, together with the heavy cover of trees, masks the bedrock to a considerable degree.

The rocks in the general vicinity consist of metamorphosed volcanic and sedimentary rocks belonging to the Chanchelulla formation of possible Devonian age. This formation is rather widespread in this region. Geology of the Helena damsite is shown on Plate 22.

At Helena damsite, the Chanchelulla formation is represented by hornblende meta-andesite with foliation which regionally trends northwestward and dips to the southwest. This trend could not be observed at the damsite however, largely because of lack of well defined bedding or foliation. Primary flow structures or banding is a common occurrence in the drill core but since the core could not be oriented, attitudes of these structural features are not known. They are usually not very clearly exposed in outcrops. Some of the banding may be due to a secondary foliation imposed upon the rock at a much later time.

When fresh, the rock is a grayish-green color, but on weathered surfaces it possesses a light-brown color due in part to hydrated iron oxide derived from the hornblende. The rock is very hard, but is well jointed near the surface and in road cuts. This jointing diminishes greatly at depth.

It is believed that the rocks were originally flows, shallow intrusions, and possibly pyroclastic beds. Alteration has masked many of the criteria for identifying such rock types. At one locality on the right abutment, 1,500 feet downstream from the axis, rock with small subparallel feldspar crystals resemble part of an original volcanic flow. On the left abutment a drill hole intersected several thin beds of material that had somewhat of a clastic texture and may represent tuffaceous material.

These rocks when originally extruded constituted a pyroxene andesite. Subsequent metamorphism has altered the pyroxene to hornblende and has caused the replacement of a large part of the groundmass by calcite. The original shape of the pyroxene grains has been maintained, but in thin sections the optical properties, especially the pale pleochroism of the mineral, reveals the alteration to hornblende.

Mineralization is common as numerous calcite and quartz veins intersect the rock core. Most of the veins are less than one-half inch in thickness. Pyrite is obiquitous in and near the mineralized zones.

Exploration of Foundation Rock

A total of nine diamond drill core holes were drilled at the site. These consisted of three on the right abutment, four on the left, and two in the channel area, one from each side of the river so as to cross at depth under the channel. Locations of the drill holes are shown on Plate 22, and information concerning water test data and the attitude and drill depth of the holes is summarized in Table 10. Elevations and locations of the drill holes were surveyed several months after the drilling program was complete.

The holes are roughly in line with the proposed axis. They range in depth from about 52 to 175 feet, with the total aggregate footage being nearly 1,200 feet. Water pressure tests were conducted whenever possible.

Foundation Conditions

Right Abutment. The abutment rises steeply from the channel area at a slope of about 85 percent to an elevation of about 1,500 feet, where it decreases to about 70 percent.

. Part of the right abutment, especially in gullies, is covered by talus or a mixture of talus and soil cover. This material averages less than 3 feet in thickness, but the thickness varies from 1 foot on ridges to as much as 13 feet in gullies or breaks in slope. About 13 feet of such material was encountered in hole RA-3, but it is possible that this may include some badly broken and weathered bedrock. In many places bedrock is exposed at the surface such as where drill holes RA-1 and RA-2 were located.

Bedrock on the right abutment consists entirely of grayish-green massive hornblende meta-andesite. Except for the hornblende crystals, which are up to one-quarter inch in diameter, the rock is very fine-grained and dense. It is only slightly fractured below the estimated depth of stripping, and will provide a very satisfactory foundation. One core sample tested from hole RA-1 had an unconfined compressive strength of 13,680 psi.

A small shear or fault zone is exposed in a roadcut about 1,100 feet downstream from the axis. It consists of a zone 1 foot wide from which water was issuing at the rate of about one-half gpm. No displacement could be observed across it.

Below a drill hole depth of 30 feet in hole RA-1 and a depth of 40 feet in hole RA-2, water pressure tests indicated that the rock is tight. A pressure of 300 psi could be maintained with very little water loss. Fractures in hole RA-3 evidently are not nearly as tight as in the other two holes on the right abutment, as the maximum pressure obtainable during water testing of the hole was 65 psi at a water loss rate of about 4 gpm.

Core recovery was very good in all three drill holes. After drilling through overburden and the zone of heavy weathering, core recovery improved markedly with an accompanying decrease in number of fractures and increase in general freshness of the rock.

On the basis of water tests conducted, it is believed that the rock will grout satisfactorily and the take will be moderate.

Stripping estimates for a concrete dam are given normal to the ground surface and apply to the area beneath the entire foundation area. Fresh, sound rock is expected to be encountered at a depth of probably not more than about 35 feet and possibly even less. The upper 3 feet of this interval consist of soil and talus. Immediately below, the soil zone is rather badly weathered and jointed rock becomes progressively fresher, harder, and less broken.

Although a zone of rather heavy fracturing occurs between 42 feet and 50 feet in hole RA-1, there is fresh rock between 26 and 42 feet. Inasmuch as the water pressure tests did not indicate this zone to be open, and at least 15 feet of fresh rock exists above it, it is believed that excavation below this 42- to 50-foot zone will not be necessary. Thus, the above stripping estimates are considered conservative.

Channel Section. The river averages about 100 feet in width and flows in a rather steep-sided canyon. Bedrock is quite well exposed in the channel area, except along parts of the right side which have been covered by riprap to protect the highway. Stream sands and gravels are believed to be present to a depth of about 15 feet.

Both drill holes in the channel, RC-1 and LC-1, penetrated hornblende meta-andesite similar to that found on the right abutment. Core recovery in RC-1 was 94 percent. Most of LC-1 was drilled with a core liner in the barrel and the core recovery was only 81 percent, but it is believed that if a proper core liner had been used, the recovery would have been as high as that of RC-1.

Two core samples were tested for unconfined compressive strength; one sample, from RC-1, tested at 15,000 psi; the other one, from LC-1, tested at 25,500 psi.

The rock in the channel section probably can be grouted effectively, and it is estimated that the grout take will be moderate.

The condition of the rock is good with only a moderate amount of fracturing. Some iron staining on fractures exists to depths as great as 40 feet in RC-1 and 45 feet in LC-1.

Satisfactory water tests were obtained above 59 feet in RC-1 and above 82 feet in LC-1. The interval from 59 feet to 119 feet in RC-1 was able to hold a pressure of 300 psi during water testing with only a $2\frac{1}{2}$ gpm loss. During the test of the interval from 82 feet to 102 feet in LC-1, a pressure of 300 psi was maintained with a 5 gpm loss.

Stripping estimates are given normal to the surface of the channel and apply to the area beneath the entire foundation area. It is expected that the channel contains about 15 feet of sand and gravel, all of which must be removed. In addition, 15 feet of slightly to moderately jointed rock should be excavated to expose sound rock. There is no evidence that a fault is present in the bedrock beneath the channel fill.

Left Abutment. This abutment rises quite uniformly from the channel area at a slope of about 80 percent. Except for a few resistant knobs, bedrock is poorly exposed. It is covered by a heavy growth of vegetation and by a relatively thin but wide-spread veneer of talus and soil cover. This overburden is estimated to average about 10 feet in thickness, but thicker local accumulations do occur. Drill hole LA-1 and LA-3 each drilled through about 32 feet of overburden, whereas LA-2 and LA-4 encountered only 13 feet and 11 feet, respectively.

Bedrock on the left abutment is the same grayish-green hornblende meta-andesite that occurs on the right abutment and in the channel area. The rock is massive, fine-grained, and slightly to moderately fractured below the estimated depth of stripping.

Three core samples were tested for unconfined compressive strength. Two from hole LA-1 gave values of 11,700 psi and 16,800 psi, and one from LA-2 tested at 27,200 psi. These values indicate that rock similar to the type tested is far above the minimum strength required, and that it will provide a very satisfactory foundation.

Apparently the fractures are somewhat more open on this abutment than on the right as indicated by water pressure tests. The only interval in which a pressure of 300 psi could be maintained was between 99 feet and 130 feet in hole LA-1 where a water loss of about 4 gpm occurred. The fractures, however, do not appear to be badly weathered, numerous, or closely spaced. The rock below the estimated stripping depth is as fresh as that on the right abutment below the same drill hole depth.

Core recovery was somewhat lower than that obtained on the right abutment, but the core losses occurred largely in the badly fractured and weathered zones, which will be stripped rather than distributed throughout the entire interval. It is believed that the rock will grout satisfactorily and that the grout take will be moderately high.

Stripping estimates are given normal to the ground surface and apply to the area beneath the entire foundation. Depth at which sound rock was encountered varied considerably from one hole to the other. Hole LA-3, located on the lowest portion of the abutment, reached sound rock at a drill depth of 30 feet, or about 22 feet measured normal to the surface. Sound rock was not encountered in LA-1 until about 72 feet, or about 40 feet below the bottom of the overburden. In LA-4, overburden was encountered to a depth of about 11 feet and sound rock reached at a drill depth of 26 feet, or about 22 feet as measured normal to the surface. About 11 feet of overburden was present in LA-2, and sound rock was reached at 23 feet. The rock in the interval between the overburden and sound rock is weathered and rather badly broken.

In summary, the average stripping on the left abutment will consist of removing about 10 feet of overburden comprised of soil cover and talus, in addition to possibly as much as 30 feet of fractured rock with varying degrees of weathering.

Spillway

An overpour type of spillway is proposed for a concrete dam at Helena site. Stream gravels extend to an estimated depth of 15 feet, but below that, hard, massive, relatively unweathered hornblende meta-andesite should be exposed. Although the rock is considered to be very resistant to scour and plucking action, protection will be required where the overflow impinges on the channel.

A spillway for a fill-type dam should probably be located on the right abutment, since sound rock is apparently at a shallower depth there than on the left abutment. However, the difference is so slight (about 5 feet) that the spillway could be located on the left abutment as well if the topography is more suitable. The drill holes indicate that sound rock is at an average depth of about 35 feet below ground surface on the right abutment; but at the elevation of the spillway the depth would be greater, possibly about 50 feet. Cut slopes should be stable at about 1:1 in the upper 50 feet and about 1/2:1 below 50 feet. An estimated 50 percent of the rock excavated above a depth of 50 feet, and all the rock excavated below 50 feet, could be salvaged for use as rockfill.

Diversion Tunnel

A diversion tunnel 1,500 feet long is proposed through the right abutment. It would be driven entirely through the hornblende meta-andesite. The proposed tunnel would penetrate sound hard rock throughout its length except at the portals. No significant shear zones were noted that would project into the tunnel line. Because of the relative hardness, lack of weathering, massive character, and absence of extensive jointing and shearing, tunnel conditions should be good.

Reservoir Area

Rocks underlying the reservoir area consist mainly of meta-sediments and meta-volcanic rocks of the Chanchelulla formation, and schists of the much older Abrams and Salmon formations. Granitic type rocks, mainly hornblende diorite, quartz diorite, and granodiorite intruded into these rocks during the Jurassic period. All of the original sediments and volcanics have more or less been regionally metamorphosed. Structurally the rocks trend northwest.

The rocks within the reservoir area are impermeable; no buried stream, along which leakage could occur, was observed during a reconnaissance of a large part of the area. There is believed to be no danger of leakage from the reservoir.

A study of the silting conditions for the Trinity River Project indicated that the silting rate in that portion of the drainage basin would be less than 0.3 acre-foot per year per square mile of drainage area, and that the silting would have no appreciable adverse effect on the reservoir for a considerable length of time. Also, the construction of Trinity Dam will reduce the silting rate in the Helena Reservoir. Silting is not expected to be a problem in the reservoir.

There are many existing, small mining claims on gravel deposits along the section of the river which would be flooded by the reservoir. However, there is presently little mining activity in the proposed reservoir area, and the value of the claims is probably relatively small.

Construction Materials

Investigation for construction materials included two dozer trenches at Coopers Bar, 4 miles upstream from the damsite, testing of samples from Coopers Bar to determine their suitability for use as concrete aggregate, auger drilling to locate and sample impervious material, and a visual examination of the rock at the site to evaluate its suitability for use as rockfill.

Concrete Aggregate. Over 11 million cubic yards of dredger tailings are present at Coopers Bar, 4 miles upstream from the site. The deposits consist of moderately well graded gravels overlying sand. Grading, absorption, specific gravity, sodium sulfate, mortar bar, and Los Angeles Rattler tests indicate that the tailings are potentially suitable for use as concrete aggregate, but they will require washing and screening to obtain the desired grading. State Highway 299 passes near the edge of the deposit.

Transition Material. If a rockfill dam were constructed at the site, the tailings at Coopers Bar would be well suited for use as transition material. Processing to obtain the required grading would probably be necessary. Also, the gravels overlie the sand-sized material.

Rockfill. The rock which comprises the foundation of the damsite would be excellent for use as rockfill, and sufficient amounts can be obtained adjacent to the site. The rock is hard, dense, tough meta-andesite. Six tests to determine the unconfined compressive strength of the rock core obtained by diamond drilling ranged from 11,700 psi to 27,200 psi, and averaged 18,300 psi. Two tests to determine the apparent specific gravity of the core gave values of 3.12 and 2.88. At the site, it is massive to slightly foliated with joints which are well developed near the surface. The intensity of jointing will diminish somewhat with depth, but the joints will have considerable influence on the shape and size of the individual blocks developed by quarrying. The spacing of the joints varies from several inches up to several feet, with an average of about 2 feet. Observation of the blocks apparently derived from blasting in the road cuts near the axis indicates that quarried rock would be angular and have a suitable shape, but much of it would be larger than desirable for use as rolled rockfill. A dumped rockfill section in the dam would eliminate considerable secondary blasting, or wasting of the oversize material. Quarry fines should not be excessive. If the quarry were located between the elevation of the channel and the top of the dam, stripping of an estimated 30 feet of material would be required to reach sound rock. Extending the quarry to a higher elevation would require deeper stripping. An estimated 75 percent of the stripped material could be utilized in the fill, the soil and highly weathered rock in the impervious zone, and the less weathered rock in the rolled rockfill zone.

Impervious Material. The total required bank volume of impervious material for a 600-foot high dam was estimated to be 3 million cubic yards.

The nearest source of impervious fill is located at Eagle Ranch about 1-1/2 miles south of the site, as shown on Plate 23, "Location of Construction Materials, Big Bar and Helena Damsites". This area represents an old erosional surface and is underlain by a deep mantle of residual soil and slopewash. The elevation ranges from 3,300 to 2,500 averaging about 1,600 feet above the channel elevation of the site.

This area was explored by one auger hole drilled nearly at the upper limit of the deposit. No further sampling was possible at that time owing to adverse weather and lack of access. The hole was drilled to the maximum depth of the auger (25 feet) without any indication of proximity of bedrock. The material tested consists of a clayey sand (SC to CL) with a range of the liquid limit from 39 to 33 and a plasticity index from 16 to 12. The samples contained nearly no gravel size material and had a range of minus 200 sizes from 20 to 51 percent finer by weight.

Based on these test results, the materials of Area I-6 (see Plate 23) appear to be suitable for an impervious core. Further sampling and testing is necessary for an adequate evaluation of the design criteria of this material. The total bank volume of Area I-6 is estimated to be 4.3 million cubic yards assuming a conservative overall usable depth of 7 yards.

Additional sources of impervious fill are located about 4 miles southwest of the proposed site. These areas are designated I-3 through I-5 (see Plate 23) and are more fully described under Big Bar Damsite.

Conclusions

1. The foundation is suitable for either a concrete gravity or fill-type dam 600 feet high.

2. There will be no problem with leakage from the reservoir. The grout take for a grout curtain beneath the dam is expected to be moderate.

3. Construction materials for a rockfill dam are available within a 4-mile radius. Excellent material for rockfill is available adjacent to the damsite.

Recommendations

1. Investigation of the nearest source of impervious material consists of one auger hole and geologic mapping to outline the areal extent of the borrow area. Additional drilling should be performed to verify that adequate material is available, and the properties of the material should be determined by testing.

2. Additional foundation drilling would be desirable in the following areas:

a. Along the spillway alignment to determine depth to sound rock.

b. In or near the channel to determine depth of gravels and configuration of bedrock surface.

c. On both abutments to determine depth to sound rock, and to refine the stripping estimates.

TABLE 10

HELENA DAMSITE
SUMMARY OF EXPLORATION

Foundation Drill Hole No.	Date Started / Date Completed	Location	Elevation	Inclination	Total Depth (ft)	Typical Water Losses	Rocks Encountered and Geological Properties	Percent Core Recovery (excl. of overburden)
RA-1	1- 9-57 / 1-23-57	Right abutment on old highway on axis	1607	45° N41W	150	Interval tested: 80 ft Loss: 0.12 gpm/ft @ 125 lb/in^2	Fractured, veined, meta-andesite	94
RA-2	2- 1-57 / 2-14-57	Right abutment 200 ft upstream from axis	1746	60° N56W	129	Interval tested: 63 ft Loss: .052 gpm/ft @ 300 lb/in^2	Fractured, veined, meta-andesite	86
RA-3	2-14-57 / 3- 5-57	Right abutment on axis	1465	56° N28W	153	Interval tested: 61 ft Loss: .057 gpm/ft @ 60 lb/in^2	Fractured meta-andesite veined with calcite	95
RC-1	1- 7-57 / 1-23-57	Right channel, on axis	1297	60° S40E	175	Interval tested: 60 ft Loss: .041 gpm/ft @ 300 lb/in^2	Fractured diorite porphyry veined with calcite and quartz	94
LC-1	1-31-57 / 2-13-57	Left bank, on axis	1305	50° N36W	140	Interval tested: 41.5 ft Loss: 0.22 gpm/ft @ 40 lb/in^2	Fractured meta-andesite with calcite and quartz veins	81
LA-1	3- 4-57 / 3-21-57	Left bank, 80 ft down axis	1429	50° S57E	130	Interval tested: 66 ft Loss: 0.27 gpm/ft @ 260 lb/in^2	Fractured, veined meta-andesite	98

TABLE 10 (Continued)

Foundation Drill Hole No.	Date Started / Date Completed	Location	Elevation	Inclination	Total Depth (ft)	Typical Water Losses	Rocks Encountered and Geological Properties	Percent Core Recovery (excl. of overburden)
LA-2	3-11-57 / 4- 1-57	Left side, on axis	1760	59° S46E	150	Interval tested: 89 ft Loss: 0.14 gpm/ft @ 110 lb/in^2	Twenty-three feet of overburden and weathered rock overlie fractured, veined porphyritic meta-andesite	97
LA-3	2-13-57 / 2-18-57	Left bank on axis	1308	11° S36E	52	Interval tested: 41 ft Loss: 0.23 gpm/ft @ 75 lb/in^2	Fractured meta-andesite veined with calcite, quartz	74
LA-4	3-29-57 / 4-15-57	Left side, 80 ft upstream from axis	1617	35° S27E	102	Interval tested: 43.5 ft Loss: 0.34 gpm/ft @ 100 lb/in^2	Poor core recovery and 100 percent water loss to a depth of 22 ft. Below 22 ft, there was good core recovery of fractured, veined meta-andesite	88

Big Bar Damsite

Big Bar damsite is situated on the Trinith River in the $NE\frac{1}{4}$ of Section 4, T4N, R8E, HB&M. The proposed axis is located 1,400 feet downstream from the mouth of Monkey Creek. Excellent access to the area is provided by State Highway 299 which traverses the lower right abutment.

A topographic map of the damsite at a scale of 1 inch = 400 feet and a contour interval of 20 feet was prepared by the Department of Water Resources. The reservoir area is shown on the following USGS quadrangles at a scale of 1:62,500, C.I. = 100 feet or 50 feet: Ironside Mountain, Hyampom, Helena, Hayfork, and Weaverville.

Description of Project

Big Bar damsite, an alternate to Helena damsite, would develop a firm annual water yield of about 500,000 acre-feet. This water will be diverted from the Trinity River system to the Sacramento River system via the Clear Creek Tunnel No. 2 or the alternative Cottonwood Creek Tunnel.

Preliminary design of the cost curve category indicates a rolled rock or dumped rockfill section with a thick impervious core and a narrow transition zone. Cost estimates were computed for four elevations: 1,400, 1,550, 1,650, and 1,800. The total amount of embankment materials in cubic yards range up to 32.4 million. A 180,000-cfs chute or side channel spillway with a flip bucket is planned for the upper left abutment. A 20-foot-diameter diversion tunnel will be located through the lower right abutment.

The entire foundation area is underlain by rock units of the Chanchelulla formation which have a rather uniform N15-20°W strike of foliation. The prevalent dip of foliation is to the northeast (upstream and into the right abutment) although reversals of dip are common. Locally, the structural relationships are complex.

The most important structural feature is a fault zone that is well exposed in the channel area at the proposed axis. The fault zone is approximately 150 feet in width and the attitude of shearing within the contorted and crumpled meta-sediments varies from N15W to N25W with a vertical dip. Mineralization consists of pyrites and yellow sulfate deposits; seeps are common. Although covered by vegetation and slopewash, a continuation of this fault zone can be inferred from the following evidence: (1) a saddle (elevation 1,617) on the left abutment north of Deer Creek, and (2) extensive shearing that trends N20W and is located along State Highway 299 roadcuts south of Whites Bar Creek.

A narrow fault zone is exposed in the channel about 1,300 feet upstream from the mouth of Monkey Creek, but this fault is beyond the foundation area.

At the surface the Chanchelulla rock is highly jointed and has been broken into moderately blocky to very blocky and seamy units. The strikes of the prominent joint sets are N25-30E, N75-80E, and N55-60W.

Numerous shear zones, usually located in slate members, vary from 0.5 to 5 feet in width and were observed along the channel and in State Highway 299 roadcuts.

Foundation Conditions

Right Abutment. The right abutment has a uniform average slope of 1.5 to 1. Near the downstream toe of the foundation area the abutment contours curve to the northeast to conform to the change in direction of the Trinity River. The slope is covered by a moderate growth of trees and brush.

The right abutment is underlain by meta-sediments with lesser amounts of schist and greenstone. Terrace deposits occur between elevations 1,180 and 1,220. Exposures of rock are fair between elevations 1,200 and 1,300 feet and poor higher up the abutment. The alignment of spotty, widely spaced outcrops tentatively disclosed two narrow belts of schist that cross the abutment in a northwest trending direction.

The rock units trend N10-30W and dip from 40°-70°NE. The prominent fault located in the channel area could not be traced across the lower right abutment because of an extensive cover of soil and slope-wash. Several small shears were noted in which less resistant meta-sediments were highly fractured and altered to a black clayey gouge.

Channel. The channel section averages about 260 feet in width, has a gentle gradient and is relatively free of vegetation. The only fresh outcrops exposed at the damsite occur in the channel area. Bed-rock consists of complexly interbedded meta-sediments, schist, and meta-volcanics that abruptly pinch out along strike. Outcrops are not continuous across the channel but are overlain by alluvial sands and gravels. These stream channel deposits are estimated to vary from 10 to 40 feet in depth and average 25 feet.

The strike of the strata in the channel vary from N40W to N-S and dips range from 50°NE to vertical to 70°SW. These attitudes indicate tight folding that is local and discontinuous.

A major fault as previously mentioned crosses the channel at the proposed axis. There is no evidence for a fault alignment that coincides with the channel, but subsurface data is needed to verify this viewpoint. No important shears were mapped in the channel area.

Left Abutment. The left abutment is steep (1.5:1) and it is cut by several ravines in the foundation area. A soil cover supports a heavy growth of brush and timber. Outcrops are scarce but it is assumed the left abutment is composed of the same rock types found in the channel and right abutment. Attitudes were obtained from a few spotty outcrops of schist. The strike varies from N-S to N20W and the dips are vertical to 80SW. Additional surface mapping and subsurface data are needed to determine the extent of the major fault zone and the distribution of rock types on the left abutment.

Spillway. A chute or side channel spillway with a flip bucket and training walls is proposed for the upper left abutment. The exact location and design of the spillway will depend upon the crest height of dam selected. Until the final spillway location is determined, only general geologic factors can be presented.

The spillway excavation will probably encounter these rock types in order of abundance: slate and slaty shale, schist, chert and meta-volcanics. Except for the overlying soil the entire excavation will be by hardrock blasting with an estimated 60 percent of the material suitable for rolled rockfill.

A large portion of this rolled rockfill material will consist of moderately soft and erodable arigillaceous metasediments (slate and slaty shale) that will produce rock fines in excess of 10 percent. This type of construction material requires pervious filter drains and special placing techniques to avoid excessive compressibility.

Side slopes should be stable at 1:1 with berms every 50 feet. The spillway alignment parallels foliation that will generally dip into the excavation along the southwest cut slope. This may cause minor sliding or rockfalls; but since the cut slopes are shallower than the average dip of foliation, no serious stability problems are expected.

The entire chute section should be lined. The angle of re-entry into the Trinity River is favorable and scour will not seriously erode the competent meta-volcanics at this point. The dry gouge associated with a fault zone may present some erosion problems.

Diversion Tunnel. A 20-foot diameter tunnel is planned for the lower right abutment. The tunnel will encounter meta-sediments, at least two narrow belts of schist and minor lenses of meta-volcanics. The foundation rock of both the inlet and outlet portals is covered by terrace deposits.

The tunneling conditions should vary from hard and foliated to very blocky and seamy. In fault and shear zones, however, completely crushed rock with clay gouge should be anticipated. Foliation will strike across the tunnel at an angle of 35° to 50° and dip steeply to NE. The tunnel will cross the major fault zones about 1,000 feet upstream from the outlet portal.

Stripping Estimates. Stripping estimates are given normal to slope for a rockfill or rolled rockfill dam 665 feet in height.

Stripping Estimates

Impervious Core	Pervious Shell
Right Abutment	
20 feet average - remove all soil and talus plus 10 feet of weathered and jointed rock.	10 feet average - remove all organic material, soil, talus and loose rock.
Channel	
25 feet average - remove all alluvial sand and gravels plus 5 feet of jointed rock.	20 feet average - remove all alluvial sands and gravels.
Left Abutment	
25 feet average - remove all soil and talus plus 10 feet of weathered and jointed rock.	15 feet average - remove all organic material, soil, talus, and loose rock.

All channel alluvium should be removed from beneath the pervious shell so as to determine the adequacy of the underlying foundation rock. Terrace deposits and road fill, estimated to be 20 feet in depth, must be removed from the lower right abutment.

The fault zone will require over-excavation of 10 to 15 feet of sheared rock and gouge and should be backfilled with concrete.

Additional foundation preparation will consist of localized dental work in narrow shear zones, limestone crevices, and highly weathered rock.

Foundation Grouting. At the surface the joints and fractures in the rock are closely spaced and moderately open. The configuration and tightness of the joints and fractures at depth is not known, but a grout estimate of one sack of cement per linear foot of hole should seal the foundation along the cutoff trench. The success of grouting in fault and shear zones that contain clayey gouge is doubtful, however.

Construction Materials

Impervious Material. An adequate volume of suitable impervious fill is available from borrow areas I-1 through I-5 about 1.0 to 2.5 miles upstream from the site (see Plate 23). The five potential borrow areas were explored by 20 auger drill holes to a maximum depth of 55 feet. Representative samples were obtained and submitted to the laboratory for testing. Test results are summarized in Table 11.

Area I-1 consists of old colluvial deposits which overlie the Weaverville formation. The material has an average composition of gravelly, clayey sand based on 15 mechanical analyses from six auger holes, and appears to be well suited for impervious core material. The deposit contains numerous thin boulder horizons which caused some difficulty in field sampling operations. These lenses contain boulders of up to 2 feet in diameter and are expected to produce 5 to 10 percent of oversize material (over 6 inches in diameter) during excavation.

A preliminary volume calculation of borrow area I-1 indicates that about 4,600,000 bank cubic yards of material are available, with an average depth of 15 yards.

Borrow area I-2 consists primarily of fine-grained deposits of the Weaverville formation. A considerable volume of the sediments has been removed by hydraulic operations. The remaining material varies in depth from 50 to 5 feet and is underlain by Cretaceous sediments. The average composition of this deposit based on three auger holes and six laboratory analyses is sandy clay. About 2 million cubic yards of this material are present in area I-2 based on an average depth of 8 yards. The results of materials testing are summarized in Table 11.

Borrow area I-3 consists of old colluvium which overlies deeply weathered rock units of the Chanchelulla formation. This area was explored by two auger drill holes from which five samples were obtained. Although no compaction tests were performed, this material appears to be similar to impervious borrow area I-1 (sandy clay) and design criteria for area I-1 may be used in the preliminary planning stages. The total available volume of material is estimated at 1,100,000 yards.

Borrow areas I-4 and I-5 are underlain by a deep deposit of residual soil derived from intensely weathered metamorphic units of the Chanchelulla formation. Six auger holes were drilled to a maximum depth of 24 feet and 15 samples of materials were taken. Preliminary test results indicate that this material has an average composition of clayey and/or sandy clay and can be used in the impervious core section. No compaction or secondary testing has been performed on this material to date. The total estimated volume of material available from areas I-4 and I-5 is 11 million cubic yards.

Rockfill. Investigated rockfill sources consist of three potential quarries plus the rock salvaged from the spillway excavation. Properties of rock from three areas, R-1 to R-3, are listed in Table 11.

Quarry R-1 is located about 5 air miles east of the damsite and contains a virtually unlimited supply of excellent rockfill. The rock is a meta-andesite to meta-diorite (greenstone) with occasional thin meta-sedimentary interbeds. Overall, the rock is hard, dense, brittle, slightly foliated to massive, and moderately jointed.

Diamond drilling and unconfined compression testing of this rock at Helena damsite indicates that it should provide excellent dumped rockfill. The unconfined compression test results ranged from 12,000 to 27,000 psi.

Quarry fines (less than 3 inches in diameter) produced in normal quarry operations in this material should not exceed 10 percent by volume.

Quarry area R-2 is located within a 1.5-mile radius of the proposed site and contains approximately 80 million bank cubic yards of material. Based on reconnaissance geologic mapping, the following rock types are found in R-2: quartz mica-schist -- 75 percent; chert -- 20 percent; and slate -- 5 percent.

The quantity of fines (less than 3 inches in diameter) produced during blasting of this deposit may be as high as 30 percent by volume owing to intense fracturing and foliation of the rock. Extensive testing is needed before the suitability of this quarry area for rolled rockfill can be ascertained.

Quarry area R-3 is located on the north bank of Trinity River less than one-half mile downstream of the site, and contains an estimated volume of 40 million bank cubic yards. Rock types consist of slate and chert with minor amounts of limestone, greenstone, and schist. Near the surface the rock is highly jointed, foliated, and sheared locally.

Quarrying of this material will produce a large proportion of fines and platy fragments. Extensive study is required to determine the suitability of this material.

Pervious and Filter Materials. Borrow area P-1 at Del Loma (see Plate 23), about 3.5 miles from the site, consists of about 1 million cubic yards of pervious channel alluvium and approximately 3,500,000 cubic yards of semi-pervious terrace deposits. The terrace deposits would require extensive processing in order to produce suitable filter material. An extensive borrow investigation is required to determine the characteristics and grading of this material.

Borrow area P-2 at Cooper's Bar about 12 miles east of the proposed site via State Highway 299, contains over 11 million cubic yards of pervious sand and gravel. These deposits have been extensively dredged and are overall well graded, with coarser gravel overlying finer sand and silt.

In 1957, testing by the Department of Water Resources concrete laboratory disclosed that the tailings were potentially suitable for concrete aggregate. The tailings are well graded and passed the following tests: organic impurities after washing, absorption, soundness, abrasion, and reactivity.

Conclusions

1. Preliminary investigation indicates the foundation is adequate for a dumped or rolled rockfill dam 605 feet in height. The prominent fault zone that trends across the foundation area must be thoroughly investigated, however.

2. The stripping estimates beneath the cutoff section of a rockfill dam are: right abutment -- 20 feet, channel section -- 25 feet, and left abutment -- 25 feet.

3. Sufficient quantities of construction materials are available within a reasonable haul distance of the damsite.

4. a. Suitable dumped rockfill is available within a 5-air-mile radius.

   b. Only limited information is available on the quality of rolled rockfill material located within the damsite area.

   c. Suitable impervious core material is available within a 1.5-air-mile radius.

   d. Only limited amounts of natural drain materials are available in the damsite area.

5. Cursory examination indicates a spillway located on the upper left abutment and a diversion tunnel located through the lower right abutment will be satisfactory.

Recommendations

1. A complete construction materials investigation with emphasis on the quality of rolled rockfill material salvaged from the spillway cut is necessary.

2. Exploratory drilling, trenching, and geophysical investigation of the damsite should be performed with emphasis on fault and shear zones.

3. Detailed geologic mapping of the damsite on a topographic map of suitable scale (1 inch equals 200 feet) is required.

TABLE 11

BIG BAR DAMSITE
CONSTRUCTION MATERIALS--TEST DATA

Material	Hole No.	Bank Density lbs/ft³		Loose Density lbs/ft³		Compacted Density lbs/ft³				ø° (1)	C ton/ft²	K ft/day
		Dry	Moist.	Swell	Moist. Dens.	Shrink.	Dry Dens.	Dens. @ Opt.w.	Saturated Density			
I-1 Slopewash (impervious)	8	117.3	123.5 5% nat. moist.	25%	98.7	5%	123.4	138.8 @12.5w.	141.3	Total 12.2° Effective 35.8° (Maximum size 3/4")	Total .45 Effective 0	0.00006 (2)
	9	118.6	124.5 5% nat. moist.	25%	99.7	5%	124.8	139.9 @12.1w.	142.7			0.51(?)
I-2 Weaverville (impervious)	2	102.5	110.7 8% nat. moist.	25%	88.5	3%	105.7	126.6 @19.8w.	129.9			
	3	115.9	125.2 8% nat. moist.	25%	93.9	3%	119.5	136.7	139.7	Total 14.5° Effective 28.7° (Maximum size No. 4)	Total 0.3 Effective 0	0.0002

(1) Shear tests were run on consolidated undrained samples.
(2) Settlement permeability - final load 24 ton/ft^2.

Note: See Plate 23 for location of borrow areas.

TABLE 11 (Continued)

BIG BAR DAMSITE
ROCKFILL

Quarry Area	Rock Types	Specific Gravity	Dry Unit Weight in Bank lbs/ft^3	Percent Swell to Loose	Loose Unit Weight (dry) lbs/ft^3	Percent Swell in Place to Fill	Unit Weight in Fill lbs/ft^3	Saturated Unit Weight in Fill lbs/ft^3
R-1	Meta-andesite Meta-diorite	3.00	187.5	67	111.5	33	141.1	156.4 Porosity 25%
R-2	Schist and Chert	2.59	167.5	67	100.5	33	126.5	140.0 Porosity 22%
R-3 and Spillway Excavation	Slate and Chert	2.68	167	77	96	33	125	141.0 Porosity 25%

Burnt Ranch Damsite

Burnt Ranch damsite is located on the Trinity River in the SW$\frac{1}{4}$ of Section 13 and the SE$\frac{1}{4}$ of Section 14, T5N, R6E, HB&M, approximately 1 mile upstream from the settlement of Burnt Ranch. The axis drilled is located on the USGS Ironside Mountain quadrangle about 500 feet downstream from Collins Bar Creek at Box Canyon, a narrow constriction of the river. At the time of exploration, this site was considered for an arch dam. It should be noted that since completion of the exploration at the above described axis, other schemes have evolved which indicate that a rockfill structure, located slightly downstream, should be considered.

Purpose and Scope

A program of diamond core drilling and geologic mapping at the site was performed from January through May 1957. At that time a single arch structure 330 feet in height (to elevation 1230) was being planned.

The exploratory drilling program consisted of nine diamond drill holes with an aggregate footage of 942 feet. Three holes were drilled on the right abutment and four on the left abutment along the axis. In addition, the channel section was cross-drilled by two core holes. These holes were designed to detect the presence of faulting or weak zones and the maximum depth of the channel fill along the axis. All holes were water tested where feasible and as often as thought necessary to determine the relative fracturing and fracture permeability of the rock encountered. The abutment holes were drilled in the direction of maximum applied stress on the abutments by the proposed arch dam (about 5 degrees downstream from the tangent to the proposed arch). The exception is drill hole LA-4 which was designed to intersect the prominent quartz vein located near the arch dam axis. A summary of drilling exploration is presented on Table 12.

Geology of the Site

As shown on Plate 24, Geologic Map and Section, Burnt Ranch Damsite, the foundation rock at the axis consists of fine-to-coarse-grained dioritic rock. This intrusive body appears to grade from one grain size to another and no distinct zonal grain size trends were noted during the investigation. Zones of subsequent intrusion or auto-brecciation now recemented (or recrystalized) were also noted throughout the area.

Jointing in the diorite is very prominent at the site. Slight joint movement is indicated by slickensiding and smeared pyrite crystals occurring along many of the fractures. In some cases the pyrite has been so highly sheared that a mirror-like joint surface has been created.

A detailed joint mapping program was not undertaken; however, a general study revealed the presence of numerous joints as shown on the geologic map (see Plate 24). A general observation is that several joint systems exist in the diorite at the site. Areas of diorite closer to the upstream margin of the intrusive body have a prominent, nearly horizontal joint set, whereas further downstream a steep set predominates. A detailed study of jointing in the damsite and adjacent areas would prove useful in cut slope stability studies, and in determining the orientation of grout holes.

The serpentinized contact zone at the upstream edge of the diorite body is a distinct and important geologic feature. The zone varies in width from about 40 feet in the channel area to over 100 feet near the crest of the left abutment. In general, the zone is composed of hard lumps of serpentine-appearing rock in a sheared matrix of green clayey material. This zone is highly susceptible to erosion and the material has a low shear strength.

The meta-sediments found upstream from the axis were not studied in detail during the early investigations inasmuch as they were not involved with the proposed concrete dam. In general, the meta-sedimentary rocks appear to present no foundation problems as they are quite hard and stable.

The serpentine landslide deposits occurring both up- and downstream from the site may present foundation difficulties. These deposits were not studied specifically in the early investigation. The main concern would appear to be whether or not these deposits must be completely removed from beneath the proposed fills or whether the design can be modified to accommodate them. Inasmuch as the rockfill portion of the proposed dams would be placed on the landslide material, they probably should be stripped prior to rock placement. Exploration is needed to confirm the nature and depth of these deposits prior to any final design. Examples of the general cut slope instability of these landslide materials are seen to the west of the site. Natural slopes in these weak materials vary; however, slopes as flat as 1:10 are not uncommon. In most cases the movement of these slides would appear to be a type of "earth-flow" phenomena.

Right Abutment. Due to the height of the concrete structure under earlier consideration, geologic mapping during the investigation extended only to about elevation 1,400. The continuation of the contact zone shown on the geologic map is interpretive. Surface mapping revealed no conspicuous petrographic differences -- the diorite was observed to grade from fine through coarse-grained with no apparent controlling feature. The prominent gully on this abutment approximately along the line of section A-A may possibly be due to intersecting joint systems. Such a system has been mapped near the head of this gully. A rather thick quartz vein outcropping just upstream from RC-1 strikes at approximately right angles to the channel and dips about 45 degrees downstream. During the early phases of the investigation it was thought to be a "zone of weakness". Although jointing has accentuated its presence, no decrease in strength was noted while drilling through this vein. In one case, the vein and country rock were cored as a continuous piece.

The previously discussed slickensided joints were quite numerous in the drill cores; however, position orientation was not possible due to core grinding. These slickensided features are probably due both to the effect of shearing forces on the intrusive and perhaps the effect of gravity acting on the jointed rock in the abutments.

In drill holes RA-2 and RA-3, a change of rock type was noted. In RA-2, at 52 feet, the dioritic rock changed beyond a narrow shear or weak rock zone to a basic igneous rock type not previously recovered. Core recovery was reduced while drilling this rock and a similar rock in hole RA-3. Two possibilities exist to explain these basic igneous rocks not previously cored. The first is that the diorite contact dips steeply to the south (on the right abutment) and the holes completely penetrated the diorite and encountered the so-called "contact zone" material. The most likely explanation is, however, that the rock encountered is the northerly extension of basic igneous dikes outcropping upstream on the right abutment. Petrographic examination of the drill cores should supply the correct answer to this problem. Prediction of tunnelling conditions through the right abutment is dependent upon the interpretation of the above situation.

Channel Section. No specific different geologic features were noted in the channel section although a relatively wide zone of recrystallized brecciated rock is found there. All fractures and joints appear much tighter than those observed in the abutments. Drill hole RC-1 crossed the prominent quartz vein described above and confirmed the surface observations that this was not a weak feature of the site. This vein, varying in width from 6 inches to 1 foot, cuts completely across the site.

The intersecting channel holes, RC-1 and LC-1, encountered only the previously described diorite and thus confirmed the presence of rock at least to their point of intersection.

Left Abutment. The same general rock types and conditions are found on this abutment as on the right abutment. Pyritization, although not uncommon elsewhere, appears to be more concentrated on this abutment. The pyrite was primarily noted to occur along joint systems. Drill hole LA-4, which was designed to intersect the prominent quartz vein, gave the same results as RC-1. No movement or shearing in the vicinity of this feature could be interpreted from the recovered core. All the left abutment drill holes indicated the generally blocky nature of the jointed dioritic rock.

Water Tests and Grouting

Core hole water pressure testing indicated the general openness of may of the joints at the site. Water takes were high even under low pressures. On several occasions during water testing, water was heard traveling through a joint a short distance from the surface although no leaks to the surface could be seen. A brief summary of water test data is presented on Table 12.

A comprehensive grouting program is needed for either a concrete or fill structure on this jointed dioritic rock. Not only would the abutments require grouting to insure against leakage, but sufficent grouting would be necessary to consolidate the jointed mass to resist compressive forces. The extensive jointing would also require an elaborate drainage system -- perhaps with abutment drainage tunnels.

The rather high water takes and the observed open nature of the joints indicates grout take will be quite high. In addition, grouting should be done with a packer which allows for a specific joint to be isolated and grouted individually. Grout mixes to be used must be begun thin to insure complete coverage. Care will have to be taken to insure an efficient caulking program, otherwise grout will be lost through the open joint systems. Carefully designed drilling of several holes to the same joint from different elevations would serve as a check on the grouting efficiency and also insure complete grouting of the joint in question.

Stripping Estimates

The exploration program was undertaken to determine the feasibility of a concrete arch dam. The axis for this structure was along the line of holes shown on the geologic map of the site. The exploration and mapping performed for the above structure covered only a small portion of the abutment areas which would be included beneath a large fill-type dam. Stripping estimates for both types of structures are discussed below.

Concrete Arch Dam. Elevation 1,200 forms an approximate line between the zone of soil accumulation and the zone of rock outcrop. Above elevation 1,200, to approximately elevation 1,400, the soil accumulation is variable but will probably average 5 feet. In addition to the soil zone, a thin weathered zone may exist and if so must be removed. Unconfined compression testing of the diorite cores indicates the rock has sufficient strength to support the proposed structure. Thus the only problem would appear to be selection of the least jointed site and an adequate grouting program.

The foundation area below elevation 1,200 is essentially devoid of soil and thus foundation shaping would appear to be the only construction requirement. The channel section will require little preparation except shaping and dental work in irregular channel areas. The configuration of the bedrock channel was not determined during the early program; however, the existence of an irregularly eroded channel cannot be overlooked.

Rockfill Dam. The stripping estimate for a rockfill dam is presented below. Foundation shaping to flatten the abutment slopes prior to fill placement is necessary because below elevation 1,200 vertical to overhanging slopes are found. In most cases shaping to flatten the slopes will exceed the estimated stripping depth.

Right Abutment. Beneath the rockfill zone it is estimated that approximately 3 feet of overburden must be removed above elevation 1,200 to smooth the irregular surface. This will remove the broken rock, weathered material, and soil accumulation. Below elevation 1,200 and beneath the rockfill zone approximately 50 percent of the foundation area will require stripping of about 3 feet to shape and remove weathered rock. The remaining 50 percent can be cleaned hydraulically and dental work performed.

Above elevation 1,200, approximately 5 feet is estimated to be the stripping depth beneath the transition and impervious zones. This should remove all loose material. Below elevation 1,200, irregularly shaped areas estimated at 25 percent of the foundation area will require removal of approximately 3 feet to smooth the foundation. The remaining 75 percent can be cleaned hydraulically and dental work performed.

The channel section should require only shaping and flattening of slopes plus dental work. In the cutoff section, as mentioned previously, a concrete plug is probably required. The estimated depth of the channel section, including gravel deposits, is 50 feet, or to elevation 850.

Left Abutment. The rockfill zone above elevation 1,200 is estimated to require the removal of approximately 10 feet of loose material. Below elevation 1,200 the rockfill zone stripping estimate is the same as the right abutment.

The transition and impervious zones stripping estimate above elevation 1,200 is approximately 10 feet of loose material and an additional 3 feet of broken and jointed rock. Below elevation 1,200 these zones are estimated to have the same stripping characteristics as the right abutment.

Spillway

A spillway location on the right abutment has been considered for a high concrete dam or the rockfill structure. For any of the dam heights studied, the spillway would cross the serpentized contact zone. In addition, for several of the design heights, the spillway would partially be located in the meta-sedimentary rocks.

From upstream to downstream the spillway would encounter the meta-sediments, the contact zone, and the dioritic intrusive rocks. Little is presently known of the jointing in the steeply dipping meta-sedimentary rocks. However, general field observations indicated these rocks to be quite stable on almost vertical highway roadcuts. Cut clopes would probably have to be designed flatter on the dip slope side of the cut. This rock does not require concrete lining.

The contact zone materials should present an entirely different type of problem since exposures indicated the zone to be composed of sheared serpentine-like material with approximately 50 percent of clayey gouge. If the zone is assumed to be nearly vertical, then the primary engineering problem would be the supporting of the concrete spillway structure. As noted previously, this zone is readily eroded and therefore must be protected.

The possibility exists that the contact zone may dip easterly into the hill. A rather severe hillside stability problem would thus be created by excavation from below for a spillway structure.

Progressing downstream the spillway would encounter the previously discussed dioritic rock. The spillway chute excavation will be in the dioritic rock and no construction difficulties are anticipated. Although the jointing pattern is not known, it appears reasonable to assume that the diorite can remain unlined throughout the length of the chute. Design considerations can allow for a moderate amount of "Block plucking" caused by high velocity water flow.

Diversion Tunnel

Tunneling conditions in the three type of materials -- meta-sediments, contact zone, and diorite -- are estimated to be as follows:

Meta-sediments - No support except perhaps in occasional highly jointed zones; rock bolts sufficient. Small water flows and only from jointed zones. Moderate overbreak due to the platy nature of the foliated rock.

Contact Zone - Full support required but not squeezing ground; extremely short bridging time. Essentially no water (due to fines) except at meta-sedimentary and diorite contacts. Little or no overbreak.

Diorite - Estimate only 10 percent support in badly jointed zones; no support for remainder. Joint spacing versus diversion tunnel size may increase support.

Moderate amount of water but very rapidly draining. Water anticipated throughout this rock type due to widespread jointing. Low overbreak if blasting sufficiently controlled.

Construction Materials

Construction materials for Burnt Ranch damsite have been studied at a reconnaissance level only. Locations of construction materials are shown on Plate 25.

Aggregate. Two areas of gravel deposits for concrete aggregate were located during the investigation. These areas are at Don Juan Point and at Del Loma.

The Don Juan Point deposit is located about $3\frac{1}{2}$ miles upstream and the Del Loma deposit about 8 miles upstream from the site. The Don Juan Point materials are in an abandoned river terrace deposit and the investigation revealed a relatively high percentage (5 to 10 percent) of fines and oversize material which must be removed from the deposit prior to aggregate use. In addition, the percentage of weathered metamorphic gravel and sand sizes make the deposit questionable as a source for concrete aggregate.

The Del Loma materials are recent river gravels and older deposits which have been worked for gold. Due to the apparent "fine-free" nature of these deposits, they should be considered the prime source for this type of concrete aggregate. A crushing and sizing operation is necessary for production of suitable aggregate.

The dioritic rock at the site appears suitable for aggregate. Any rock spoils from construction in this rock could be utilized, after processing, as aggregate.

Many minor terrace and gravel deposits are located upstream within easy access. Due to their limited quantities, however, they were not studied during the early investigation.

The source area for China Slide is fractured dioritic rock and this material has been used for highway fill material; however, it does not appear suitable for concrete aggregate.

Impervious Material. A thorough study of impervious materials has not been made; however the following materials are potential sources:

1. Serpentine landslide deposits. These deposits are generally widespread along the western side of the Trinity River in the vicinity of the site. No samples were taken of this material and soil tests are therefore not available. The finer-grained portions would appear to be suitable for impervious fill material. Due to the nature of the serpentine parent material which constitutes the major portion of these deposits, the clay fraction may prove to have undesirable characteristics. Tests are necessary to confirm the presence of deleterious clay minerals.

2. Colluvial and mixed landslide deposits. Associated with the previously discussed landslide deposits are mixed landslide and weathered materials which would also appear to be suitable for impervious fill material. This general group of materials is located downstream and to the west of the site -- between State Highway 299 and the ridge crest.

3. Weathered bedrock. Although not known to exist in the immediate vicinity of the site, deeply weathered meta-volcanic and meta-sediments would make excellent impervious fill material. The prime areas would appear to be south and west of the site -- the general outcrop areas of the previously mentioned rock types.

4. Terrace deposits. Terrace deposits, such as those described at Don Juan Point, might prove to be suitable for high strength impervious fill. However, such materials are not essential in the current design inasmuch as the rockfill section does not require a high strength impervious zone. In addition to the gravelly type older terrace deposits, Tertiary deposits (Weaverville formation) may exist in the vicinity of the site. Many of these deposits are seen in high bluffs upstream along the Trinity River. One deposit, possibly of this type, was observed downstream and westerly from the site along the crest of Hennessy Ridge.

Rockfill. The best source for rockfill material would appear to be the dioritic rock from the site area. Exploration will disclose zones of less jointing, probably northerly from the site, which should be exploited as a quarry site. The dioritic rock, in areas where jointing is not extreme, will produce blocky rockfill material.

A relatively small yardage of meta-sedimentary rock can be salvaged from excavations for appurtenant works. This rock can be utilized for rockfill material; however, it will probably be of a slabby, tabular nature.

TABLE 12

BURNT RANCH DAMSITE
SUMMARY OF EXPLORATION

Foundation Drill Hole No.	Date Started / Date Completed	Location	Elevation	Inclination	Total Depth (ft)	Typical Water Losses	Rocks Encountered and Geological Properties	Percent Core Recovery (excl. of overburden)
RA-1	4- 2-57 / 4-10-57	Right abutment on axis 100 ft above channel	1000	42° N5W	115.1	Interval tested: 66.5 ft Loss: .08 gpm/ft @ 300 lbs/in^2	Medium- to coarse-grained meta-diorite with calcite fracture fillings and iron staining	100
RA-2	4-17-57 / 4-26-57	Right abutment on axis	1100	44° N5W	97.6	Interval tested: 73.5 ft Loss: .07 gpm/ft @ 300 lbs/in^2	Gray, medium-coarse grained, extensively fractured meta-diorite with extensive fractures, calcite, and quartz veins	98
RA-3	5- 3-57 / 5-13-57	Right abutment on axis	1180	53° N15E	100	Interval tested: 58.5 ft Loss: 0.15 gpm/ft @ 300 lbs/in^2	Meta-diorite with quartz and calcite fracture fillings	79
RC-1	4- 4-57 / 4-23-57	Right channel on axis	900	60° S37W	138	Interval tested 51.5 ft Loss: 0.13 gpm/ft @ 300 lbs/in^2	Medium-coarse grained meta-diorite with calcite veins, fractures, and slip surfaces	100

TABLE 12 (Continued)

BURNT RANCH DAMSITE
SUMMARY OF EXPLORATION

Foundation Drill Hole No.	Date Started --------- Date Completed	Location	Elevation	Inclination	Total Depth (ft)	Typical Water Losses	Rocks Encountered and Geological Properties	Percent Core Recovery (excl. of overburden)
LC-1	1-18-57 ------- 2- 6-57	Left channel, on axis	890	72° N38E	125.2	Interval tested: 51 ft Loss: .001 gpm/ft @ 300 lbs/in^2	Medium-coarse grained meta-diorite with quartz, calcite, and pyrite fracture fillings	97
LA-1	2- 8-57 ------- 3- 6-57	On axis, approx. 100 ft above LC-1	790	45° S80W	150.2	Interval tested: 17.2 ft Loss: .009 gpm/ft @ 290 lbs/in^2	Fine-medium grained meta-diorite with quartz and calcite veins and slip surfaces present	94
LA-2	3-11-57 ------- 3-18-57	On axis, left abutment about 200 ft above channel	1100	45° N85W	71.2	Interval tested: 41.8 ft Loss: 0.27 gpm/ft @ 200 lbs/in^2	Fractured veined medium-coarse grained meta-diorite	96
LA-3	3-21-57 ------- 3-27-57	On axis, left abutment, 2 ft from LA-2	1100	40° N25W	50	Interval tested: 41.5 ft Loss: 0.49 gpm/ft @ 180 lbs/in^2	Fine-coarse grained, veined meta-diorite	91
LA-4	3-18-57 ------- 4- 2-57	Left abutment, approx. 30 ft upstream from axis	1100	41° S5E	95	Interval tested: 61 ft Loss: 0.07 gpm/ft @ 220 lbs/in^2	Fine-coarse grained, veined meta-diorite	91

Clear Creek Tunnel No. 2

The proposed Clear Creek Tunnel No. 2 is a major feature of the North Coastal Area development scheme. This tunnel will convey surplus water from the Trinity River into the Sacramento River drainage. A geological investigation was made to determine the physical factors along the most favorable tunnel alignment that would aid in estimating preliminary cost and design.

Reconnaissance geologic mapping of a 130-square-mile area was conducted during the winter of 1960 and the summer of 1961. Approximately 18 days in the field were spent mapping surface geology. Topographic maps available for this area are published in 15-minute series by the USGS and include the Hayfork quadrangle of 1951, the Weaverville quadrangle of 1950, and the French Gulch quadrangle of 1944. Aerial photographs of this region are available from the USGS, U. S. Forest Service, and the California Department of Water Resources. Subsurface data were available from the U. S. Bureau of Reclamation's (USBR) Clear Creek Tunnel.

Description of Project

Clear Creek Tunnel No. 2 will divert about 1,800,000 acre-feet of water per year from the proposed Big Bar or Helena Reservoir on the Trinity River to the proposed Tower House Reservoir on Clear Creek. This water will then flow down Clear Creek and through Whiskeytown Reservoir, the proposed Kanaka, Saeltzer, and Girvan Reservoirs, and terminate in a reservoir at Iron Canyon on the Sacramento River.

Although the optimum physical dimensions for this tunnel have not been determined, the following tentative statistics will be presented for estimating purposes for a tunnel with invert elevation of 1,500 feet at the inlet portal:

Type of tunnel	Horseshoe section, steel-reinforced, concrete-lined
Length of tunnel	20.5 miles
Diameter of tunnel	21.0 feet lined
Inlet portal elevation	1,500 feet at Trinity River
Outlet portal elevation	1,350 feet at Mill Creek
Access shafts	Vertical, concrete-lined

No. 1	190 feet deep at Reading Creek
No. 2	1,170 feet deep at Grass Valley Creek

Location and Access

The region investigated lies in portions of Trinity and Shasta Counties and is roughly bounded on the north by the Trinity River, on the south by the 31N-32N township line, on the east by Clear Creek, and on the west by Hayfork Divide. The proposed tunnel alignment trends in an easterly direction across this area.

State Highway 299 provides excellent access to the general area. In addition, a network of well maintained county and U. S. Forest Service roads and unimproved logging roads traverse the mapped area.

Location of Alignment

The proposed tunnel was aligned: (1) to place the major portion of the tunnel in competent, stable rock; (2) to avoid zones of weakness whenever possible; (3) to cross regional structure at right angles; (4) to avoid passing under the Trinity River with low tunnel cover; (5) to provide the shortest tunnel length from established portal invert elevations; and (6) to provide shaft locations with good access and reasonably shallow depth to tunnel grade.

The proposed 20.5-mile tunnel alignment is shown on Plate 26, "Geologic Map and Section, Clear Creek Tunnel No. 2". From the inlet portal on the Trinity River (SW$\frac{1}{4}$, Section 33, T33N, R10W, MDB&M) the tunnel line will trend S56°E for 4.0 miles, then east for 15.1 miles, and finally N35°E for 1.4 miles terminating at the outlet portal on Mill Creek (T34N, R7W). This alignment is based on surface reconnaissance mapping with limited subsurface data.

The tunnel will slope toward the east, dropping from an elevation of 1,500 at the inlet portal to 1,350 feet at the outlet portal. A proposed access shaft No. 1, located on Reading Creek (NE$\frac{1}{4}$, Section 13, T32N, R10W) will extend vertically downward from a collar elevation of 1,660 to a sump several feet below a tunnel invert elevation of 1,470 feet. Vertical access shaft No. 2, at elevation 2,575 on Grass Valley Creek (NE$\frac{1}{4}$, Section 17, T32N, R8W), will have a depth to invert of about 1,170 feet.

Rock Conditions

The area of investigation is underlain by the geologic units described and shown on Plate 26, "Geologic Map and Section, Clear Creek Tunnel No. 2". The proposed tunnel will penetrate approximately 42 percent of the Abrams formation, 4 percent of the Devonian meta-volcanics, 15 percent of the Bully Choop intrusive complex, 37 percent of the Shasta Bally batholith, and 2 percent of the Shasta Bally contact metamorphic zone. The physical properties of these units will be discussed below.

Abrams Formation. Tunneling conditions in the Abrams formation are considered to be good overall. This unit consists of quartz-mica schist with lesser amounts of chlorite schist, hornblende schist, marble, and quartzite.

At tunnel grade these rocks will generally be fresh, tough, hard, and well indurated. Drilling for blast holes will be slow and blasting should be relatively expensive because of the high quartz content of the rock.

Schistosity is usually well developed and often contorted in this formation but the resistance to parting along schistosity planes is expected to be good. However, if blasting is heavy the schist may have a tendency to split along planes of schistosity and produce large detached slabs. When the schist is more massive, large blocks may occasionally spall from the roof of the tunnel and require conventional support or rock bolts for safety.

It will be difficult to maintain smooth tunnel walls when schistosity is strongly developed because slabs parallel to the schistosity tend to break away, forming ragged surfaces. This factor will increase the overbreak and require additional concrete backfill behind the tunnel lining.

If other variables are assumed to remain constant, the attitude of schistosity planes determines to a large extent the degree of overbreak and amount of support needed. Few supports are necessary where schistosity dips steeply and crosses the tunnel line, while moderate to heavy support is needed where schistosity is flat or parallel to the tunnel. In flat-lying sections especially, the rocks tend to break away from the roof as they attempt to reach a more stable arch configuration.

Rock stability in the tunnel is expected to be very good when the rock varies from hard and schistose to massive, moderately jointed. Occasional zones of weakness will contain less competent rocks that are sheared or closely fractured. These less stable rocks will vary from moderately blocky and seamy to very blocky and seemy.

Devonian Meta-Volcanics. The average tunneling conditions in the Devonian meta-volcanics are considered to be moderately good. Along the tunnel line these rocks consist of intercalated meta-andesite, meta-rhyolites, and meta-rhyolite porphyry with minor amounts of chlorite and actinolite schist. Because this unit borders the Hoadley fault zone and Shasta Bally batholith, the rocks have been recrystallized, intruded by dikes and veins, and closely fractured with minor faults and shear zones common.

The meta-andesites (Copley greenstone) vary from highly foliated to massive and are hard and moderately brittle. When sheared or faulted the meta-andesites have been altered to a soft and weak chlorite or actinolite schist. The meta-rhyolites and meta-rhyolite prophyries (Balaklala rhyolite) are massive to weakly foliated, hard to very hard and brittle. When subjected to nearby pressure this brittleness has caused the acidic meta-rhyolite to shatter in zones adjacent to faults.

Powder and drilling requirements should be of low cost overall because of: (1) closely spaced joints associated with the Hoadley fault zone, and (2) zones of crushed rock fragments and clay gouge caused by localized faulting and shearing.

Since the proposed tunnel will trend normal to foliation, the best possible advantage of rock strength is gained. Rock stability in this portion of the tunnel will probably depend more on local structural conditions than any other factor.

Rock conditions in the Devonian meta-volcanics will vary from: (1) hard and foliated to massive, moderately jointed in the most stable areas; (2) moderately blocky and seamy to very blocky and seamy adjacent to fault and shear zones; and (3) completely crushed with clay gouge in fault and shear zones.

Bully Choop Intrusive Complex. Tunneling conditions in the Bully Choop body are expected to be highly variable, ranging from poor to good. The tunnel will encounter gabbro and minor amounts of diabase and hornblende schist along the borders of the intrusive complex. In a relatively narrow zone in the central portion of the body, the tunnel will traverse periodotite, locally serpentinized.

At tunnel invert the unaltered rock will be hard, tough, heavy, and relatively massive. When the rock is partially altered, serpentine minerals are developed on slip surfaces and along fractures. Occasionally, irregular pods of rock completely altered to serpentine may be encountered. The serpentine will be soft, closely fractured, and highly sheared and may cause very heavy pressure on tunnel supports.

Except for highly altered zones, the cost of drilling and blasting should be high because of the tough, massive character of the rock. For safety reasons, steel support or suitable rock bolts will be necessary when intersecting joints or fractures produce blocks that tend to fall from the tunnel arch.

Tunneling conditions in unaltered Bully Choop rocks will vary from massive, moderately jointed when joints are widely spaced to moderately blocky and seamy or very blocky and seamy when closely spaced fractures are present. In altered rock the tunneling conditions will range from completely crushed with clay gouge to squeezing rock, moderate depth.

Shasta Bally Batholith. The Shasta Bally batholith will probably present the most variable tunneling conditions. Rock stability may vary from excellent (unsupported) to poor (earth tunneling methods). This unit will normally consist of fresh, hard, tough biotite-hornblende quartz diorite intruded by varying numbers of acidic and basic dikes and sills.

Although average tunneling conditions should be good, localized narrow areas of bad ground will be encountered. Some of the types of unfavorable conditions likely to occur are briefly discussed below:

1. Along some faults and fractures the rock may be chemically altered by hydrothermal solutions to form seams of clayey gouge and narrow zones of angular fragments surrounded by thin films of clay. If this clay is of the montmorillonite type, it will slowly expand upon absorption of water and develop sections of squeezing, swelling ground. Additional support, grouting off water inflows, and installation of tunnel lining should remedy these squeezing, swelling sections.

2. The stability of the rock in sections adjacent to faults is expected to be poor. Pressures caused by faulting can destroy the bonding forces between minerals and produce crushed material of sand, silt, and clay size. If no chemical alteration has occurred, the finer sizes (silt and clay) will not behave like true clays, but will have the characteristics of sand. Locally this crushed material will produce running ground and require earth tunneling procedures.

3. In the central part of the batholith under a high depth of cover, conditions are favorable for spalling and popping rock. This condition, commonly caused by release of residual stresses in rigid rock masses, often occurs in fresh, brittle, massive, and hard granitics. The rock tries to establish a more stable section by spalling thin, curved slabs from the walls and arch. Steel supports or rock bolts with steel mesh must be installed to safely advance the tunnel heading.

Power costs should be highly variable depending on whether the rock is hard and massive with attendant high costs, or locally crushed so that the tunnel can be advanced by spading.

Tunneling conditions should be excellent when the rock is hard and intact to massive, moderately jointed. When jointing is strongly developed the rock will vary from moderately blocky and seamy to very blocky and seamy. Local conditions of bad ground will produce completely crushed but chemically intact material to squeezing rock at moderate depth.

<u>Shasta Bally Contact Metamorphic Zone</u>. The contact metamorphic aureole bordering the Shasta Bally batholith should, in general, afford good rock stability. These metamorphic rocks consist of foliated schist, gneiss, and amphibolite. Injections of granitic rock and quartz along the foliation planes (Migmatites) increase the strength of this unit.

Since these rocks are hard, tough and recrystallized, blasting and drilling costs will be relatively high. Blasting should be closely controlled since the rocks are brittle and overbreak can easily occur. Moderate support should control the blocky condition created by the intersection of foliation and closely spaced primary joints.

When hard and foliated or moderately blocky and seamy rock is encountered, support will be widely spaced. Closely spaced support will be required in sections of the tunnel where the rock is very blocky and seamy or completely crushed with clay gouge.

Structural Conditions

Detailed structural conditions along the tunnel line will be discussed below and are shown on the geologic map and section (see Plate 26).

The attitudes of foliation observed at the surface could vary greatly at tunnel depth; surface outcrops are often slumped and, in some cases, probably overturned. Geologic contacts and structural features have been projected to tunnel grade assuming uniform dip.

Folds. From the inlet portal to Reading Creek, the tunnel line will traverse the western limb of the regional synclinorium (compound syncline). The predominant trend of schistosity in this area is to the northwest with dips varying from 25° to 60° northeast. The proposed tunnel will parallel schistosity so overbreak should be above normal, especially near Reading Creek where the dips are shallow.

The tunnel line will cross the synclinorial axis east of Reading Creek and traverse the remainder of the Abrams formation normal to the predonimant trend of schistosity. In this section of the tunnel overbreak should be at a minimum.

The proposed tunnel will cross the Bully Choop complex and the Shasta Bally dome at a 45° to 50° angle to primary flow structure. In the Mill Creek area the eastern dipping homocline structure expressed by foliation in the Devonian meta-volcanics will be penetrated normal to structure. This is highly desirable in this brittle and closely fractured rock.

Faults. The tunnel will cross at least four major zones of weakness: the Hadley fault zone, the Bully Choop intrusive contacts, and the trough of the synclinorial axis.

The most prominent structural feature encountered by the proposed tunnel will be the Hoadley fault zone. In addition less prominent faults and shear zones will commonly occur at tunnel grade but they should not greatly impede tunnel progress.

The Hoadley fault zone, about 100 feet wide, trends N60°W and dips from 50° to 60° northeast in the vicinity of the tunnel line. It is a normal fault with the northeast block depressed an undetermined distance. A wide transitional area of strongly fractured rock, minor faults, and shear zones is adjacent to the Hoadley fault zone and produces very blocky and seamy conditions.

Although surface evidence is poor near the tunnel line, subsurface data from the USBR Clear Creek Tunnel indicates that the Hoadley fault zone contains:

1. About 40 feet of intensely contorted, crushed breccia and soft chlorite gouge.

2. Approximately 60 feet of more resistant rock showing occasional lenses of silicified hard rock; closely spaced intersecting joints produce a very blocky condition.

3. Poor stability conditions overall that require steel support at 2-foot centers with invert struts.

Zones of weakness that may cause considerable difficulty will be located along the borders of the Bully Choop and Shasta Bally intrusive bodies. These areas may be hydrothermally altered and contain a considerable thickness of clay gouge. In addition, the wall rock will have been disrupted by the force of the intrusion, creating areas of poor stability (contact breccia zones).

The trough of the synclinorial axis may be an area of poor stability. Closely spaced support will be necessary if crumpled, strongly fractured rock occurs in this region of low cover.

<u>Joints</u>. Joints are developed in all rock types but are expected to be the most troublesome in the igneous intrusive bodies.

In the Shasta Bally Batholith, well developed, intersecting joints will produce an unstable, blocky condition that will cause considerable overbreak. According to USBR geologists, these well developed and persistent joints (slip planes) are generally coated with a film of gouge, indicating minor movement. Slip planes were a major cause for the large amounts of steel support used in the USBR Clear Creek Tunnel. These conditions will probably apply to the unaltered portions of the Bully Choop body as well.

In foliated rocks jointing can contribute to heavy overbreak when: (1) joints occur in closely spaced intersecting trends; or (2) the trend of the tunnel is adverse to the intersection of well developed joints and foliation planes.

Water Conditions

An undetermined quantity of ground water lies above the tunnel invert in the mapped area. Measurements of water table elevations were not available, but ground water inflows in the USBR Clear Creek Tunnel were very helpful in evaluating water conditions. Recharge to ground water is principally effected by influent seepage of streams and infiltration of precipitation.

At tunnel grade all of the rocks have low porosity; however, large volumes of ground water can be stored along open fractures, foliation planes, joints, faults, and shear zones. The amount of water encountered will vary from negligible seepage to heavy flows; however, the water stored in fractures should be readily depleted when intersected by the tunnel. In general, the highest water pressure and volume will be found in fractured rock under high depth of cover.

The greatest quantities of water are anticipated: (1) in open fractures under high depth of cover -- especially in the vicinity of the Trinity-Shasta County Line and the R8W-R9W line; (2) in the synclinal trough near Reading Creek; (3) in fault zones when highly fractured rock acts as an aquifer; and (4) along the borders of the intrusive bodies where hydrothermal alteration and contact breccia zones have increased the perviousness of the rocks. For estimating purposes, five percent of the tunnel is considered as wet heading in competent rock, and one percent is considered as wet heading in incompetent rock.

Most of the observed springs were located above tunnel grade, flowing less than 5 gallons per minute, and cool in temperature. Samples of ground water analyzed by the USBR in the eastern part of the investigated area show that: (1) the dominant-type water in granitic terrain is a sodium-calcium bicarbonate with an average pH of 7.5 and total dissolved solids of 162 ppm (five samples); (2) the dominant-type water in greenstone terrain near Lewiston is a sodium carbonate with high sulfate content, an average pH of 9.5, and total dissolved solids of 154 ppm (five samples); and (3) the type of water from a fault near the confluence of Willow and Crystal Creeks is a sodium chloride with a pH of 8.5 and a total dissolved solids of 22,920 (one sample).

The Clear Creek Tunnel of the USBR has disclosed the following hydrologic conditions at depth:

1. Maximum accumulated flows of over 6,000 gpm were measured at the portal weirs. In localized zones, water occurred in quantities up to 2,000 gpm with pressures up to 410 psi.

2. Almost all water occurred in a 17,000-foot section under high cover. The water, contained in interconnected fractures, had high initial inflows and subsequently drained.

3. Six percent of the tunnel had wet, competent rock that required pressure grouting and steel supports at greater than 4-foot spacing.

4. Four percent of the tunnel had wet, competent rock that required pressure grouting and steel supports at less than 4-foot spacing.

5. 0.7 percent of the tunnel had wet, incompetent rock that required breast boards and drifts to advance the tunnel. Two bad sections delayed the tunnel advance a total of 90 days.

6. A total of approximately 74,000 sacks of cement were used to grout off water-bearing sections of the tunnel. Grouting pressures ranged from 200 psi to 1,300 psi.

7. After tunnel lining was placed, a progressive buildup of water pressure was noted. About 1,600 weep holes were necessary to release this pressure.

Gas and Temperature

Gas should not be a problem during tunnel construction. Gas samples obtained by the USBR from drill holes along the Clear Creek Tunnel disclosed minute amounts of hydrogen sulfide gas ranging from 0.3 to 1.4 ppm (16 samples). A methane-type gas was collected from a fault near the confluence of Crystal and Willow Creeks (one sample). However, no gas was detected at depth during the construction of Clear Creek Tunnel.

High temperatures are not expected at tunnel depth. Water temperatures recorded in the Clear Creek Tunnel varied from 57° to 60°F. with a maximum cover of about 2,900 feet.

Depth of Cover

The depth of cover ranges from 0 to 2,925 feet with 50 percent of the tunnel line having at least 1,500 feet of cover. Surface weathering should not exceed 150 feet in depth.

Portal and Access Shaft Conditions

At the inlet portal about 25 feet of rock must be removed in the approach cut to reach the tunnel invert elevation of 1,500 feet. This rock will be very hard quartz schist and rock stability should be excellent. The Trinity River canyon in this area is steep and narrow so the access road will be difficult to construct. There is no dump space available at the immediate portal. A power line can be constructed from Douglas City, a distance of 3.5 air miles.

An alternate inlet portal can be developed about 4,000 feet downstream but this will increase the tunnel length accordingly. The alternate location will improve the access and dump conditions but rock stability will be reduced as an unknown depth of older terrace clayey gravels must be penetrated.

Access shaft No. 1 will be constructed in Abrams quartz-mica schist. The rock should be hard, foliated, and fresh with good stability. An existing paved road and power line are within 1,000 feet of the site. Suitable dump facilities are available. A vertical access shaft would be 190 feet deep. An inclined adit, although more expensive to construct, would facilitate the handling of equipment and materials.

Access shaft No. 2 will be 1,170 feet deep vertically and constructed in quartz diorite. The rock should be hard and stable although material near the surface may be weathered. Access will be good and dump space is locally available. Electrical power can be lined from Buckhorn Station, a distance of 2 air miles.

The outlet portal will be constructed in moderately stable meta-volcanics; the rocks at the portal should be moderately to very blocky and seamy because of their proximity to a fault. The Mill Creek canyon is narrow and moderately steep with heavy vegetation. An existing private road can be extended to the portal without undue difficulty. No suitable dump sites are in the vicinity of the portal. Power can be obtained from the Clear Creek Powerhouse or from the village of Tower House.

Concrete Aggregate

Moderate quantities of apparently suitable concrete aggregate are located within the area of investigation. While considerable quantities of aggregate are located about the inlet portal and access shaft No. 1, suitable deposits are scarce near access shaft No. 2 and the outlet portal.

Stream sands and gravels and tailing deposits comprise the concrete aggregate. The largest suitable deposits near the tunnel line are located: (1) along the Trinity River at Evans Bar near Douglas City; and (2) along Indian Creek, and Browns Creek.

Tailing deposits along Clear Creek near French Gulch are not suitable because of their high concentration of weathered Bragdon slate particles.

USBR Clear Creek Tunnel Data

As constructed by Shea-Kaiser-Morrison, the Clear Creek Tunnel has a length of 10.8 miles, a finished diameter of 17.5 feet, and a gradient of 0.0032 feet per mile. It is entirely lined and has a maximum concrete thickness of 9 inches. Tunnel operations advanced from four headings: inlet portal, outlet portal, upstream from the adit, and downstream from the adit.

Equipment, usually track-mounted, consisted of: (1) a Conway mucking machine of 1 cubic yard capacity, (2) a Morgan Gantry Jumbo machine of 1 cubic yard capacity, (2) a Morgan Gantry Jumbo mounting seven drills, (3) an electric muck car hoist, and (4) side dump muck cars of 10-cubic-yard capacity. The outlet end of the tunnel was excavated with tire-mounted equipment.

Approximately 77 percent of the tunnel was supported by structural steel ranging in spacing from 0.9 to 7 feet. Rib-type steel consisted of: (1) a 6-inch, 20-pound light column at a cost of $490 per set, and (2) an 8-inch 30-pound wide flange at a cost of $785 per set.

Blasting explosives were of the gelatin type ranging from 40 to 70 percent strength. The standard practice was to use 0.3 to 0.4 pound of powder per cubic yard of rock. The most commonly used round was a 4-foot length loaded with 250 pounds of powder. A normal rock pattern was 70 to 80 holes of which 20 holes were assigned to a perimeter cut.

In areas of large overbreak, additional backfill grout mixes of 1:1 were injected under pressures of 250 to 500 psi. For rock grouting purposes, grout of 3:1 to 7:1 water-cement ratio were injected under pressures of 50 to 200 psi.

Construction Factors

To facilitate a preliminary cost estimate of tunnels, the following Terzaghi rock load factors have been adopted for use in the North Coastal area:

Rock Condition	Description	Terzaghi Load Factors
1	Hard intact rock. May be light spalling, no support required.	0
2	Massive, moderately jointed. Light support and/or rock bolts required (load may change erratically).	0.25B
3	Hard stratified or schistose. Light support and/or rock bolts required.	0.5B
4	Moderately to very blocky and seamy. Support required. Little or no side pressure.	0.35 (B+Ht)
5	Completely crushed but chemically intact. Considerable side pressure. Invert struts required.	1.10 (B+Ht)
6	Squeezing rock. Heavy side pressure. Circular support required.	2.10 (B+Ht)
7	Squeezing, swelling rock. Great depth. Heavy circular support required.	4.50 (B+Ht)

Rock conditions expected in Clear Creek Tunnel No. 2 have been grouped into three zones as follows: Zone I includes rock conditions 1, 2, and 3 and represents the most stable rock and the lowest tunneling costs; Zone II consists of rock condition 4; and Zone III includes rock conditions 5 and 6; weak incompetent rocks which will present the highest tunneling costs. Rock conditions 1 through 6 occur in all the formations in this area.

Each zone contains rocks that have similar engineering properties based on the following physical factors: (1) composition, hardness, and strength of the rock, (2) attitude of the rock and thickness of the individual strata, (3) degree of chemical alteration, (4) frequency, intensity, and attitude of joints, fractures, and faults, (5) depth of cover, and (6) water conditions. When adverse physical factors occur together in a limited zone, rock stability decreases and tunnel costs are greatly increased. The stability of rock in tunnels also depends on the size of the bore and the method of tunnel driving.

In addition to the Terzaghi load factors assigned to each zone, Department of Water Resources Bulletin No. 3 factors are also included. Bulletin No. 3 factors conveniently show the rock's hardness, support, lagging, and lining characteristics in numerical terms rather than lengthy word descriptions.

Construction factors are based on reconnaissance field work with limited subsurface data and should be used only for preliminary cost estimating. Construction factors are presented graphically on Plate 26 and tabulated in Table 13.

Zone I. Rocks in this zone include the most competent portions of the formations encountered by the tunnel line. Zone I varies from hard and intact to massive, moderately jointed, to hard and schistose (rock conditions 1, 2, and 3). The joint blocks are tight and interlocked so tunnel walls should not need steel supports. Bridging action will be good and overbreak generally slight. Rock bolting and/or arch supports on 6-foot centers will be necessary where light rock loads or spalling rocks are encountered. The excavation method can be full face. About 66.5 percent of the tunnel will encounter this zone.

Range of Zone I Factors

Terzaghi Factors	0.0	0.25B	0.5B
Bulletin No. 3 Factors			
Excavation	1.3	1.0 to 1.1	1.1
Support	0.0	0.2	0.3
Lagging	0.0	0.3	0.4
Lining	0.0	0.7	0.7 to 1.0
Percent of Tunnel Length	21	20	25.5

Zone II. Rocks in this zone include the moderately stable portion of the tunnel. Zone II varies from moderately blocky and seamy to very blocky and seamy (rock condition 4). Joint spacing will usually yield blocks greater than 2 feet in diameter although smaller joint blocks are not uncommon. Since the joints are imperfectly interlocked, occasional support of vertical walls will be needed. Bridging action will vary from good to fair. Overbreak should be moderate to high. Horseshoe steel sets at 4- to 6-foot centers with lagging will be necessary to support light to moderate rock loads and to prevent slabbing and rock falls. The rock can usually be excavated by the full face method although the top heading and branch method may occasionally be employed. About 22.5 percent of the tunnel will encounter this zone.

Range of Zone II Factors

Terzaghi Factors	0.35 (B+Ht)
Bulletin No. 3 Factors	
Excavation	0.9 to 1.0
Support	1.0 to 1.5
Lagging	1.0 to 1.2
Lining	1.0 to 1.5
Percent of Tunnel Length	22.5

Zone III. Rocks in this classification will be the most unstable and weak materials encountered by the tunnel and are usually associated with faults, shears, or chemically altered zones. Zone III varies from completely crushed but chemically intact (running ground) to crushed with clay gouge, to squeezing rock, moderate to great depth (rock conditions 5 and 6). Bridging action will be poor. Overbreak will be negligible in squeezing rock and heavy in unconsolidated material. Rock loads will be high, requiring steel supports on 2-foot centers for the arch and walls. Clay seams, fault gouge, and pods of serpentine might have squeezing characteristics requiring invert struts or a circular section. If lengthy sections of Zone III conditions are encountered, the tunnel can be advanced by the multiple drift method, top heading method, or forepoling method. About 11 percent of the tunnel will encounter this zone.

Range of Zone III Factors

Terzaghi Factors	1.10 (B+Ht)	2.10 (B+Ht)
Bulletin No. 3 Factors		
Excavation	1.5	2.0
Support	2.2	3.2
Lagging	1.8	2.0
Lining	1.5	0.5
Percent of Tunnel Length	7	4

Conclusions

1. The 20.5-mile Clear Creek No. 2 Tunnel, based on reconnaissance geologic mapping with limited subsurface data, can be constructed to satisfy geologic and engineering requirements.

2. The tunnel is comprised of the following units: 42 percent of the Abrams quartz-mica schist, 37 percent of the Shasta Bally quartz diorite, 15 percent of the Bully Choop basic intrusives, 4 percent of the Devonian meta-volcanics, and 2 percent of the Shasta Bally contact zone.

3. The tunnel will traverse about 66.5 percent of Zone I rock (unsupported to light support), 22.5 percent of Zone II rock (Moderate support), and 11 percent of Zone III rock (heavy support).

4. The tunnel can be advanced from four headings: inlet portal, outlet portal, access shaft No. 1, and access shaft No. 2. No length of heading will be greater than about 4.5 miles. The vertical distance from the surface to tunnel invert in access shafts Nos. 1 and 2 will be 190 feet and 1,170 feet, respectively. All headings are located in Zone I or II rock.

5. The tunnel will cross four major zones of weakness. Although Zone III conditions are expected in these areas, no unusual construction problems are anticipated.

6. Five percent of the tunnel is considered wet heading in competent rock and one percent is considered as wet heading in incompetent rock. High water inflows are expected in narrow zones under areas of high cover. The yield and location of these water zones cannot be predicted.

7. Natural gas, deleterious mineral waters, and high temperatures are not expected at tunnel grade.

8. The tunnel should be designed to withstand moderate earthquake shocks.

9. Sources of concrete aggregate are located within the tunnel area.

10. The maximum cover is 2,925 feet and 50 percent of the tunnel line will have at least 1,500 feet of cover.

Recommended Exploration

It is recommended that there be:

1. Detailed geologic mapping on a large scale topographic map (1 inch = 1,000 feet).

2. Geophysical surveys to determine: (a) the boundaries of the Bully Choop intrusive body, (b) the location of concealed or buried serpentine pods within the Bully Choop body, and (c) the boundaries of the Hoadley fault zone.

3. Exploratory drilling along the tunnel line to include core holes at the portals and access shafts and in the Hoadley fault zone. These holes will determine the character of bedrock and structure at depth and supply temperature and ground water data.

4. Excavation of an exploratory adit: (a) at the inlet portal to determine Zone I tunneling conditions under a considerable depth of cover; and (b) at the outlet portal to determine Zone II tunneling conditions under low cover.

5. Construction of exploratory shafts at the location of access shafts Nos. 1 and 2.

TABLE 13

TUNNELING CONDITIONS OF CLEAR CREEK TUNNEL NO. 2

Station in miles	Geology	Range of Rock Conditions	Percent of Tunnel	Rock Load in feet	Bull. 3 - Construction Factors Excav.	Support	Lagging	Lining	Estimated Steel Rib Spacing
0.0 to 4.0	Quartz mica schist, tunnel parallel to schistosity.	Hard and schistose to very blocky and seamy.	4 10 5	0.0 0.5 B 0.35 (B+Ht)	1.3 1.1 1.0	0.0 0.3 1.5	0.0 0.4 1.2	0.0 1.0 1.5	Rock bolts where needed 6-foot centers 4-foot centers
4.0 to 8.7	Quartz mica schist, tunnel normal to schistosity.	Hard and schistose to very blocky and seamy.	6 12 5	0.0 0.5 B 0.35 (B+Ht)	1.3 1.1 1.0	0.0 0.3 1.5	0.0 0.4 1.2	0.0 0.7 1.0	Rock bolts where needed 6-foot centers 4-foot centers
8.7 to 11.7	Gabbro, diabase, and peridotite with some serpentine pods.	Massive, moderately jointed to squeezing rock, great depth.	6 4 3 2	0.25 B 0.35 (B+Ht) 1.10 (B+Ht) 2.10 (B+Ht)	1.0 0.9 1.5 2.0	0.2 1.0 2.2 3.2	0.3 1.0 1.8 2.0	0.7 1.0 1.5 0.5	6-foot centers 4-foot centers 2-foot centers; invert struts. Circular supporteribs on 2-foot centers or less
11.7 to 19.2	Quartz diorite, conditions at grade highly variable.	Hard and intact to squeezing rock, great depth.	11 14 7 3 2	0.0 0.25 B 0.35 (B+Ht) 1.10 (B+Ht) 2.10 (B+Ht)	1.3 1.1 1.0 1.5 2.0	0.0 0.2 1.0 2.2 3.2	0.0 0.3 1.0 1.8 2.0	0.0 0.7 1.0 1.5 0.5	Rock bolts where needed 6-foot centers 4-foot centers 2-foot centers; invert struts. Circular support-ribs on 2-foot centers or less
19.2 to 19.6	Gneiss, amphibolite, schist and migmatite. Hoadley fault zone.	Hard and foliated to squeezing rock, moderate depth.	1 0.5 0.5	0.5 B 0.35 (B+Ht) 1.10 (B+Ht)	1.1 1.0 1.5	0.3 1.5 2.2	0.4 1.2 1.8	0.7 1.0 1.5	6-foot centers 4-foot centers 2-foot centers; invert struts
19.6 to 20.5	Meta-andesite and meta-rhyolite; tunnel normal to foliation.	Hard and foliated to completely crushed with clay gouge.	2.5 1 0.5	0.5 B 0.35 (B+Ht) 1.10 (B+Ht)	1.1 1.0 1.5	0.3 1.5 2.2	0.4 1.2 1.8	0.7 1.0 1.5	6-foot centers 4-foot centers 2-foot centers; invert struts

NOTES:
1. 5% of the tunnel is considered as wet heading, competent rock.
2. 1% of the tunnel is considered as wet heading, incompetent rock.
3. Rock loads after Karl Terzaghi.
4. Percentages of tunnel length are approximate.
5. B = width of tunnel in feet
   Ht = height of tunnel in feet

Cottonwood Creek Tunnel

The proposed Cottonwood Creek tunnel will divert an estimated 1,500,000 acre-feet of water per year from the Trinity River drainage into the Sacramento River drainage. The primary purpose of this geologic investigation was to select the most favorable tunnel alignment that would satisfy geologic and engineering requirements and be economically feasible.

A geologic reconnaissance was conducted during the fall and winter of 1960. About 22 days were spent field mapping the surface geology of a 150-square-mile area using aerial photographs and the following USGS topographic maps at a scale of 1:62,500: Weaverville, Hayfork, Chanchellulla Peak, French Gulch, and Ono quadrangles. No subsurface data were available.

Description of Project

The Cottonwood Creek tunnel will convey water from the proposed Big Bar or alternative Helena Reservoir on the Trinity River to the Selvester Reservoir on the Middle Fork of Cottonwood Creek. The West Side Conveyance System will then transport this water along the west side of the Sacramento Valley to the Glenn Reservoir Complex (see Plate 1).

Although the optimum physical dimensions for this tunnel have not been determined, the following tentative statistics will be presented for estimating purposes.

1. Type of tunnel - Concrete lined pressure conduit. Horseshoe section with steel support.
2. Tunnel length - 19.9 miles. Tunnel diameter - 17.5 feet lined.
3. Inlet portal elevation on Trinity River - 1,500 feet. Outlet portal elevation on Middle Fork Cottonwood Creek - 1,375 feet.
4. Access shaft - Vertical, 450 feet deep. Located on Browns Creek about 6.4 miles from inlet portal.

Location and Access

The region examined lies in portions of Trinity and Shasta Counties. The mapped area is bordered on the north by the Trinity River, on the south by the Middle Fork of Cottonwood Creek, on the east by Bully Choop Mountain, and on the west by Hayfork Divide. The proposed tunnel line trends in a southeasterly direction for 19.9 miles across this area.

Access to the northern portion of the region is by means of State Highway 299, the Douglas City-Hayfork County Road, and a well maintained network of Trinity County and U. S. Forest Service dirt roads. In addition, logging roads and trails facilitate movement. The southern portion of the area investigated is traversed by the Ono-Platina county road and a group of forestry, logging, and private dirt roads.

Location of Alignment

Two geologic requirements were considered most important in the location of the tunnel: (1) to place the major portion of the tunnel in the competent Siskiyou rock group, and (2) to avoid zones of weakness whenever possible.

Considering the above requirements, a 19.9-mile tunnel alignment (shown on Plate 27) is proposed. From the inlet portal on the Trinity River (SW$\frac{1}{4}$, Section 33, T33N, R10W, MDB&M) the tunnel line trends S38^{O}E for 10.8 miles, then S23^{O}E for 9.1 miles, terminating at the outlet portal on the Middle Fork of Cottonwood Creek (SW$\frac{1}{4}$, Section 30, T30N, R8W, MDB&M).

Special care was taken to locate the portals and access shaft in sound rock. The tunnel slopes toward the southeast, dropping from an elevation of 1,500 feet at the inlet portal to 1,375 feet at the outlet portal. A proposed vertical access shaft at elevation 1,875 feet on Browns Creek (Section 30, T32N, R9W) will have a depth to invert of about 400 feet. This alignment is based on surface reconnaissance mapping with no subsurface data and is not necessarily the optimum location at tunnel grade.

Rock Conditions

At tunnel grade, as shown on Plate 27, the major portion of the tunnel will traverse the Siskiyou group (88 percent) and the remainder of the tunnel will encounter the Chanchelulla group (8 percent), the Shasta series (4 percent), and possibly the Weaverville formation. Each of these units have different engineering properties which will be detailed below.

Sisikyou Group. Tunneling conditions in the Siskiyou group are considered to be good overall. This unit consists of Salmon hornblende schist, and Abrams quartz mica schist with minor amounts of chlorite schist, quartzite, marble, hornblende gneiss, and shale.

At tunnel grade these rocks will be generally fresh, tough, hard, and well indurated. Drilling for blast holes will be slow and blasting costs should be relatively high.

Schistosity will be well developed in portions of this group -- especially the quartz-mica schist and the chlorite schist -- but the resistance to parting along schistosity planes is expected to be good. When the tunnel line parallels schistosity, slight to moderate overbreak may be expected. In the more massive rocks, large blocks may occasionally spall from the roof of the tunnel and require conventional support or rock bolts.

Tunneling conditions are expected to be very good when the rock varies from hard and schistose to massive, moderately jointed. Occasional zones of weakness will contain less competent rocks with pronounced schistosity and closely spaced features. These weaker rocks will vary from moderately blocky and seamy to very blocky and seamy.

Chanchelulla Group. The average tunneling conditions in the Chanchelulla group are considered to be moderately good. Along the tunnel line this group is comprised of weakly metamorphosed meta-volcanics and slates with subordinate amounts of schist, chert, and limestone. Since the rock types differ greatly, the engineering properties of this group are highly variable.

The meta-volcanics should be the best tunneling rock within the Chanchelulla group; they are roughly foliated to massive, very hard, moderately brittle, well indurated. When foliated and sheared, however, the meta-volcanics are usually altered to a soft and weak chlorite schist. Interbedded with the meta-volcanics are slates and cherts.

At tunnel grade the slates should be fresh, moderately hard, and well indurated. Some breakage along well developed foliation planes can be expected. Where the tunnel line parallels foliation, slight to moderate overbreak is anticipated. In fault and shear zones the slates are highly contorted, exhibit fracture cleavage, and are often altered to a fat clay gouge. Where beds of banded chert with shale partings are encountered, moderate overbreak can occur. The shale partings will tend to form slip surfaces along which steeply dipping chert may slide.

Rock conditions in the Chanchelulla group will vary from: (1) hard and foliated to massive, moderately jointed in the competent meta-volcanics and schists; (2) moderately blocky and seamy to very blocky and seamy in the slates, cherts, limestones, and less competent meta-volcanics and schists; and (3) very blocky and seamy to completely crushed in fault and shear zones.

Shasta Group. The Shasta group, composed of interbedded sandstone and shale with minor amounts of conglomerate, is expected to possess fair to moderately good tunneling conditions. These beds dip 20° to 35° to the southeast and trend about normal to the tunnel line.

At tunnel invert the sandstone will be fresh, moderately hard, and well indurated. Closely spaced fractures and some parting along bedding planes classified this rock as moderately blocky and seamy.

The effects of nearby faulting have imparted to the thinly bedded, moderately soft shale a fracture cleavage. Therefore, the shale can be considered as very blocky and seamy except in fault zones where it is completely crushed with fault gouge.

Weaverville Formation. The Weaverville formation, if encountered will probably present the poorest tunneling conditions. The projection of structural data from the surface indicates the Weaverville formation will not be present at tunnel grade; however, incomplete surface evidence and unknown subsurface conditions can extend these beds to tunnel invert. Geophysical exploration may determine whether the Weaverville formation or other units -- Shasta sediments or Abrams schist -- will be encountered by the tunnel.

Poorly consolidated sandy shale and tuffaceous sediments interbedded with smaller amounts of mudstone, sandstone, conglomerate, and thin lignite seams comprise this unit. These beds strike normal to the tunnel line and dip gently to the southeast at 15° to 30°. This formation is poorly indurated and broken by faulting, and may exhibit squeezing ground if tuffaceous sediments and lignite seams are encountered.

Structural Conditions

Structural conditions along the tunnel line -- attitudes, folds, faults, and shears -- are shown on the geologic map and section (see Plate 27).

Folding. The tunnel line, which traverses the western limb of the regional synclinorium (a compound syncline), is roughly parallel to the northwest-trending regional structure. The structure generally dips 35° to 50° to the east although local variations in attitude are common.

In certain areas, such as Reading Creek Valley, Horse Mane Ridge, and Blue Nose Peak the local structure is oblique to the regional trend. At Horse Mane Ridge and Blue Nose Peak complex folding has imparted an east-west foliation to the rocks. Reading Creek Valley, composed mainly of Shasta and Weaverville sediments, is located in a down faulted block that trends normal to the tunnel line. The uniform bedding strikes to the northeast and dips from 10° to 40° to the southeast.

The attitudes observed at the surface could vary greatly at tunnel depth; surface outcrops are often slumped and, in some cases, probably overturned. Geologic contacts and structural features have been projected to tunnel grade, assuming uniform dip.

Faulting. The tunnel line will traverse three major faults which are discussed below in order of importance. In addition, many minor faults and shear zones will undoubtedly occur at tunnel grade, but they are not expected to hinder construction.

1. A complex fault zone separates the older Abrams schist from the younger Chanchelulla group near the Ditch Fork of Duncan Creek. The fault zone in this area was mapped in detail and the following tentative conclusions are proposed:

a. The boundaries of the fault zone are gradational and difficult to determine. The average width of the zone is about 1,000 feet.

b. The eastern block has apparently been thrust over the western block but it was not possible to measure the relative movement.

c. The rocks in the fault zone consist of quartz-mica schist, actinolite schist, and chlorite schist; meta-volcanics and diabase with interbedded slate; and pods of sheared serpentine at scattered intervals.

d. Foliation within the fault zone is variable; the general trend is to the northwest with steep dips to the east.

e. Rock conditions vary from moderately blocky and seamy to very blocky and seamy to completely crushed to squeezing rock, moderate depth.

2. A fault which forms the southern boundary of Reading Creek Valley has downdropped the Shasta and Weaverville sediments into the resistant Siskiyou group. This fault is normal and appears to dip steeply north. A narrow zone consisting of clayey gouge and moderately to highly broken rock surrounds the fault.

3. A probable fault forms the contact between the Salmon and the Abrams formation in Section 9, T31N, R9W. The type and direction of fault movement could not be determined. Field evidence for faulting includes a prominent shear zone in Reading Creek (Section 3, T31N, R9W) and variance in attitudes along Horse Mane Ridge.

Water Conditions

Ground water storage of undetermined quantity lies above the tunnel invert. The quantity of water is probably large because of an extensive drainage area, a relatively high water table, and a depth of cover up to 3,900 feet. Recharge to the water table is principally accomplished by a mean annual precipitation of about 35 inches, and some influent seepage by perennial streams and tributaries.

With the exception of the Weaverville formation, all of the rocks have low porosity and permeability. Thus, ground water storage and transmission will generally be along fractures, foliation, and bedding planes. The tunnel line will traverse the western limb of a synclinorium - a situation which is usually favorable from the standpoint of ground water movement. Since structures in the area dip steeply, the ground water in storage may be depleted rapidly when intersected by the tunnel.

The greatest quantities of water are anticipated: (1) in fault zones where the fault acts as an aquifer rather than a ground water barrier; (2) in highly fractured rock where the cover is high; and (3) in the weakly consolidated Weaverville formation that acts as a ground water reservoir over the Shasta series. For estimating purposes, 3 percent of the tunnel length is considered as wet heading in competent rock.

Water in the tunnel could have high hydrostatic pressures if interconnected fractures under high cover extend from the water table to tunnel grade. Thus, under a cover of 3,900 feet, a maximum pressure of about 1,600 psi could be anticipated.

Almost all springs observed were: (1) located above tunnel grade, (2) flowing less than 3 gallons per minute, (3) cool in temperature, and (4) free from sulfurous or other deleterious mineral waters. No flowing hot springs or highly mineralized springs were found. In this area, no legal problems are anticipated if springs dry up as a result of water drainage into the proposed tunnel.

The Clear Creek tunnel of the USBR has recently been completed in terrain with similar hydrologic conditions. Personal communication with USBR personnel disclosed the following information: (1) approximately 4 percent of the tunnel could be considered wet heading, (2) the major water inflows occurred in fractured rock under high cover - faults did not present serious water problems, (3) water occurred in quantities up to 3,000 gallons per minute with pressures up to 450 psi, (4) the water, contained in interconnected fractures, had high initial inflows and subsequently drained, and (5) no deleterious mineral waters or gas were encountered.

Gas and Temperature

Gas should not be a problem during tunnel construction. Small amounts of natural gas may be present in the Shasta series and Weaverville formation; however, good ventilation and immediate installation of tunnel lining in the gaseous area should solve this problem.

High temperatures are not anticipated at tunnel depth; this assumption is based primarily on the experience in the Clear Creek Tunnel.

Concrete Aggregate

Extensive quantities of apparently suitable concrete aggregate are located within the area of investigation. While considerable quantities of aggregate are located about the inlet portal and access shaft, deposits of aggregate are scarce in the outlet portal area.

Stream sands and gravels and tailing deposits comprise the bulk of the concrete aggregate. The largest deposits near the tunnel line are located: (1) along the Trinity River at Evans Bar, Steiner Flat, and near Douglas City; and (2) in Reading Creek Valley along Indian Creek, Reading Creek, and Browns Creek.

Construction Factors

Rock conditions expected at tunnel grade have been grouped into three zones to facilitate a preliminary cost estimate. Each zone contains rocks of similar engineering characteristics based on the following physical data: hardness, strength, degree of fracturing, faulting and shearing, depth of cover, water conditions, attitude of schistosity, foliation or bedding, and chemical alteration. These zones are presented graphically on Plate 27 and tabulated in Table 14.

Different Terzaghi factors are assigned to each zone to compute cost factors. Since these factors are based on reconnaissance field work with no subsurface data, they should be used only for preliminary cost estimating. The rock conditions become less favorable from Zone I through Zone III.

Zone I. Rocks in this classification include most units of the Siskiyou group. Zone I varies from hard and schistose to massive, moderately jointed. The joint blocks are tight and interlocked so tunnel walls should not need steel supports. Overbreak should be light and bridging action should be good. Rock bolting and arch supports will be needed where light rock loads are encountered. The excavation method can be full face. About 69 percent of the tunnel will encounter this zone.

Summary of Zone I - Range of Factors

Terzaghi Factors	0.0	0.25B
Bulletin No. 3 Factors		
Excavation	1.3	1.2
Support	0.0	0.2 to 0.3
Lagging	0.0	0.3 to 0.4
Lining	0.0	0.4 to 0.9
Percent of Tunnel Length	25.5	43.5

Zone II. Rocks in this zone are the Chanchelulla group, Shasta series, and less competent units of the Siskiyou group. Zone II varies from moderately blocky and seamy to very blocky and seamy. Joint spacing will usually yield blocks greater than 2 feet in diameter although smaller joint blocks are not uncommon. Tunnel overbreak will be light to moderate. Horseshoe steel sets with spreaders and lagging will be necessary to support light to moderate rock loads and loose blocks and spalling. Occasional support of vertical walls will be needed. The rock can usually be excavated full face. About 29.0 percent of the tunnel will encounter this zone.

Summary of Zone II - Range of Factors

Terzahi Factors	0.25 (B+Ht)	0.35 (B+Ht)
Bulletin No. 3 Factors		
Excavation	1.0 to 1.1	1.0 to 1.2
Support	0.5 to 0.6	1.3 to 1.7
Lagging	0.9 to 1.0	1.1 to 1.4
Lining	0.8 to 0.9	1.0 to 1.2
Percent of Tunnel Length	15.5	13.5

Zone III. Rocks in this classification occur in the Weaverville formation and in relatively narrow fault and shear zones. Zone III varies from very blocky and seamy to completely crushed to squeezing rock at moderate depth. These rocks will be completely broken by faulting or cross jointing. Rock load and overbreak will be heavy requiring closely spaced steel supports for the arch and walls. Clay seams, fault gouge, and serpentine pods might have squeezing characteristics, requiring invert struts or a circular section. Rock can be excavated by the multiple drift method or the full face method where possible. About 2 percent of the tunnel will encounter this zone.

Summary of Zone III - Range of Factors

Terzaghi Factors	1.10 (B+Ht)
Bulletin No. 3 Factors	
Excavation	1.5 to 1.7
Support	2.1 to 2.4
Lagging	1.7 to 1.9
Lining	1.5
Percent of Tunnel Length	2

Conclusions

1. Based on reconnaissance geologic mapping with no subsurface data, the 19.9-mile Cottonwood Creek tunnel can be constructed to satisfy geologic and engineering requirements.

2. The tunnel will encounter approximately 88 percent schist (Siskiyou group), 8 percent meta-volcanics and slate (Chanchellulla formation), and 4 percent sandstone and shale (Shasta series).

3. The tunnel will traverse about 69 percent of Zone I rock (unsupported to light support), 29 percent of Zone II rock (light to moderate support), and 2 percent of Zone III rock (heavy support). The inlet portal and access shaft are located in Zone I rock while the outlet portal is in Zone II rock.

4. The tunnel will encounter three major faults, all considered inactive. Although clay gouge and/or pods of serpentine are expected at tunnel grade, no unusual construction problems are anticipated.

5. Three percent of the tunnel length is considered as wet heading in competent rock. When open fractures are found under areas of high cover, moderate to large water inflows are expected. No significant quantities of hot or highly mineralized waters are anticipated at tunnel grade.

6. Small quantities of natural gas may be present in the Shasta sediments, but should not be a problem. High temperatures are not expected at tunnel grade.

7. The tunnel should be designed to withstand moderate earthquake shocks.

8. Sources of concrete aggregate are located within the tunnel line area.

9. The maximum cover is 3,635 feet and 50 percent of the tunnel line will have at least 1,600 feet of cover.

Recommended Exploration

1. Precise geologic mapping is needed on a suitable topographic map (1 inch = 400 feet) along the proposed tunnel line. Detailed traverses should be conducted to determine rock types and geologic structures expected at tunnel grade.

2. Geophysical surveys are required and should include:
   a. A resistivity and/or gravity survey to determine the thickness and water-bearing properties of the Weaverville formation that overlies the tunnel line in Reading Creek Valley.
   b. A magnetometer and/or resistivity survey to determine the extent and character of the three major faults traversed by the tunnel line.
   c. A gravity and/or seismic survey to determine the location of the Shasta series-Siskiyou group contact at depth in Reading Creek Valley.

3. Exploratory drilling is recommended along the proposed tunnel line and should include core holes at the portals and access shaft to determine the structure and character of bedrock at depth. Temperature and ground water data can be obtained in each core hole.

TABLE 14

TUNNELING CONDITIONS P COTTONWOOD TUNNEL

Station in miles	Geology	Terzaghi Factors: Rock conditions	Terzaghi Factors: Percent of tunnel	Terzaghi Factors: Rock load in feet	Bulletin 3 Construction Factors: Excavation	Bulletin 3 Construction Factors: Support	Bulletin 3 Construction Factors: Lagging	Bulletin 3 Construction Factors: Lining	Remarks
0.0 to 1.6 - Zone I	Quartz mica schist, hard; tunnel parallel to schistosity.	Schistose to massive, moderately jointed.	3 5	0.0 0.25 B	1.3 1.2	0.0 0.3	0.0 0.4	0.0 0.9	Minor spalling may occur. Light support; portal area.
1.6 to 2.8 - Zone II	Quartz mica schist, hard; trend of schistosity varies.	Moderately blocky and seamy to very blocky and seamy.	4 2	$0.25(B+H_t)$ $0.35(B+H_t)$	1.1 1.2	0.5 1.5	0.9 1.2	0.9 1.1	No side pressure. Zones of weakness.
2.8 to 6.7 - Zone I	Quartz mica schist, hard; tunnel parallel to schistosity.	Schistose to massive, moderately jointed.	7 13	0.0 0.25 B	1.3 1.2	0.0 0.3	0.0 0.4	0.0 0.9	Minor spalling may occur. Light support; access shaft.
6.7 to 7.4 - Zone II	Sandstone, shale and conglomerate; moderately hard to moderately soft.	Moderately blocky and seamy to very blocky and seamy.	2 1.5	$0.25(B+H_t)$ $0.35(B+H_t)$	1.0 1.2	0.6 1.7	1.0 1.3	0.8 1.2	No side pressure. Zones of weakness.
7.4 - Zone III	Fault zone - normal steeply dipping fault with clay gouge.	Very blocky and seamy to completely crushed.	0.5	$1.10(B+H_t)$	1.5	2.2	1.8	1.5	Considerable side pressure.
7.4 to 8.1 - Zone II	Quartz mica schist, or hornblende schist; geology at grade uncertain.	Moderately blocky and seamy to very blocky and seamy.	1.5 1.5	$0.25(B+H_t)$ $0.35(B+H_t)$	1.1 1.2	0.5 1.5	0.9 1.2	0.9 1.1	No side pressure. Zones of weakness.
8.1 to 10.0 - Zone I	Hornblende schist, hard; trend of schistosity variable.	Schistose to massive moderately jointed.	3.5 6.0	0.0 0.25B	1.3 1.2	0.0 0.2	0.0 0.3	0.0 0.7	Minor spalling may occur. Light support.
10.0 to 10.2 - Zone II	Hornblende schist, hard; tunnel parallel to schistosity.	Moderately blocky and seamy.	1	$0.35(B+H_t)$	1.0	1.3	1.1	1.1	Moderate support.

TABLE 14

TUNNELING CONDITIONS OF COTTONWOOD TUNNEL

(continued)

Station in miles	Geology	Terzaghi Factors: Rock conditions	Terzaghi Factors: Percent of tunnel	Terzaghi Factors: Rock load in feet	Bulletin 3 Construction Factors: Excavation	Support	Lagging	Lining	Remarks
10.2 – Zone III	Probable fault zone; type of movement not known.	Very blocky and seamy to completely crushed.	0.5	$1.10(B+H_t)$	1.5	2.1	1.7	1.5	Considerable side pressure.
10.2 to 11.3 – Zone II	Quartz mica schist, hard; highly folded and complex structure.	Moderately blocky and seamy.	3 2	$0.25(B+H_t)$ $0.35(B+H_t)$	1.1 1.0	0.5 1.3	0.9 1.1	0.9 1.0	No side pressure. Moderate support.
11.3 to 17.6 – Zone I	Quartz mica schist, hard; trend of schistosity variable.	Schistose to massive, moderately jointed.	12 19.5	0.0 0.25 B	1.3 1.2	0.0 0.2	0.0 0.3	0.0 0.7	Minor spalling may occur. Light support.
17.6 to 18.0 – Zone II	Quartz mica schist, hard; occasional shear zones.	Very blocky and seamy.	2	$0.35(B+H_t)$	1.2	1.5	1.2	1.1	Zone of weakness.
18.0 to 18.2 – Zone III	Complex thrust fault zone; scattered pods of sheared serpentine.	Very blocky and seamy to completely crushed to squeezing rock, moderate depth.	1	$1.10(B+H_t)$	1.7	2.4	1.9	1.5	Heavy side pressure.
18.2 to 19.9 – Zone II	Metavolcanics with some slate, chert, and limestone; foliation about normal to tunnel.	Moderately blocky and seamy to very blocky and seamy.	5 3.5	$0.25(B+H_t)$ $0.35(B+H_t)$	1.1 1.2	0.5 1.6	0.9 1.4	0.8 1.2	No side pressure; portal area. Zones of weakness.

NOTE: 1. 3% of tunnel considered wet heading, competent rock.
2. Percentages of tunnel are approximate.
3. B = width of tunnel in feet.
4. H_t = height of tunnel in feet.
5. Station measurements are from the northwest tunnel portal.

West Side Conveyance System

The West Side Conveyance System consists of a series of reservoirs, connected by open cut tunnels, stretching from the Middle Fork of Cottonwood Creek in Shasta County to Thomes Creek in Glenn County, a distance of nearly 40 miles.

The West Side Conveyance System is a vital part of the North Coastal water development plan with a two-fold purpose. The conduit conveys the surplus and flood flows of the Western Sacramento Valley drainage and also transports the water of Main Fork Trinity River into the Glenn Reservoir. The Trinity River water is diverted into the West Side System through the 20-mile Cottonwood Creek Tunnel. At a later development stage the West Side System can also transport the waters of South Fork Trinity, Mad, Van Duzen and Klamath Rivers.

A number of alternate plans of conveying the water into the Glenn Reservoir were investigated during the initial stages of the West Side System study. The plan described in this report was selected on the basis of preliminary geologic analysis and is subject to change.

The initial project on the West Side Conveyance System is Fiddlers Reservoir on the Main Fork Cottonwood Creek. From Fiddlers Reservoir a series of channels and reservoirs link the drainage systems of South Fork Cottonwood, Red Bank, and Elder Creeks with Paskenta Reservoir on Thomes Creek (see Plates 28 to 30).

The area of investigation is located in T23 to 29N, R6 to 8W, MDB&M. Available topographic maps consisted of the USGS Ono, Colyear Springs, and Paskenta $7\frac{1}{2}$-minute quadrangles with a scale of 1:62,500 and a contour interval of 50 feet.

Purpose and Scope

The purpose of the investigation was to prepare a preliminary cost estimate on several alternate West Side Conveyance System schemes. Based on this cost study, the most economical route was to be selected.

Geologic study consisted of reconnaissance geologic mapping of the area of investigation, a brief description of foundation conditions, availability of construction materials for the proposed dams, and a preliminary evaluation of excavation methods and slope stability of open cut channels. Geologic features of all the proposed West Side Conveyance

System damsites and channels are summarized in Tables 15 and 16, respectively. Geologic data presented in this report were obtained during the summer and fall months of 1960.

Regional Geology

The West Side Conveyance System is located in the Coast Range foothills, an area of moderate topographic relief. The highest ridges and peaks in the immediate area lie at an elevation of 1,500 feet and major stream channels have an elevation just under 1,000 feet.

The latest uplift of the area occurred in Mid-Pleistocene time. The youthful topography is characterized by sharp V-shaped canyons and rapid erosion. Major streams appear to have anteceded the latest uplift and have become entrenched.

The region is underlain by two major geologic units, the bedrock series and the Tehama formation. Bedrock includes the Knoxville formation of Jura-Cretaceous age and the Shasta-Chico series of lower and upper Cretaceous age respectively. Bedrock series are overlain unconformably by the Tehama formation of Pliocene age.

The geologic structure is readily reflected in the topographic expression of the region. Areas underlain by bedrock units consist of parallel northwest-trending rolling ridges and saddles, while flat-lying Tehama units have caused the development of an intricate, but highly characteristic, feather-like drainage pattern.

Rock Units

Bedrock Series. This unit includes the Cretaceous marine sediments of the Sacramento Valley section as well as the Knoxville formations of Jura-Cretaceous age. Due to their similar lithologic character and uniform engineering properties the bedrock series were not differentiated into formations but were treated as one broad lithologic assemblage and are referred to in this report as the Cretaceous rocks.

In the area studied, the Cretaceous rocks have a relatively uniform north to northwest strike and eastward dip. Rock types include mudstone, shale, sandstone, and conglomerate, listed in the order of relative abundance. Less resistant fine-grained sediments generally occupy saddles and valleys while sandstone and conglomerate form narrow, parallel ridges or hogbacks.

Thinly bedded mudstone and shale is by far the most abundant rock unit and constitutes up to 70 percent of the entire Cretaceous group of rocks. The rock has a characteristic black color and is found in beds averaging 1 to 3 inches in thickness. Thin interbeds of fine-grained sandstone are always present in varying amounts.

On exposure to air, mudstone and shale break down or slake into thin, platy fragments. Slaking is most intense in very thinly bedded slaty material. Where the rock is predominantly mudstone and is somewhat less finely laminated, slaking is less pronounced. Examination of stream channels and highway excavations indicates that slaking affects no more than the top foot of the exposed rock. Slaking characteristics vary greatly throughout the area studied and are affected by grain size, thickness of bedding, and attitude of the strata, as well as jointing and shearing.

Sandstone constitutes about 20 percent of the entire assemblage of Cretaceous rocks and is one of the most resistant rock units in the region. The rock is generally fine-grained, gray to greenish-gray greywacke sandstone composed of angular fragments of quartz, feldspar, and lithic grains in a matrix composed essentially of the same assemblage as the grains but extremely fine-grained. Alteration of clay and other indeterminate secondary minerals is common in the matrix material.

Several belts of Cretaceous sandstone were mapped along the Westside Conveyance System. Within these belts the sandstone occurs in beds 1 to 3 feet in thickness and contains numerous thin mudstone interbeds. Sandstone is the foundation rock of McCartney and Scheonfield Damsites, two of the more important features of the System.

Sandstone is also found in thin isolated beds, interstratified with mudstone and shale. The thickness of individual strata averages 2 to 3 inches. Several belts or zones are outlined on the geologic map where the sandstone constitutes more than 25 percent of the unit.

Conglomerate is a relatively minor although highly characteristic unit of the Cretaceous. The rock is generally hard and resistant and is commonly found interbedded with sandstone.

Tehama Formation. The Tehama formation consists of a thick accumulation of continental fluviatile sediments of Pliocene age which overlap unconformably the Cretaceous rock units. In the area studied the Tehama formation is essentially flat lying.

The formation is composed of poorly sorted unconsolidated silts, clayey silts, sands, and clayey gravels predominantly yellow and buff to red-brown in color. Units of the Tehama formation occur in discontinuous lenses, which are characteristic of flood plain deposition.

A light colored tuff bed -- the Nomlaki tuff -- is found near the base of the formation and constitutes the only marker horizon of the Tehama. Locally the Nomlaki tuff rests directly on the Cretaceous rocks.

The Tehama formation is the source of virtually all impervious fill for the proposed structures. Although no samples were obtained in the West Side area during the brief reconnaissance, an extensive study of impervious materials in the Glenn Reservoir area was completed and the test results should be applicable to the West Side projects owing to similarity of the materials.

<u>Structure</u>

The Cretaceous system forms a north to northwest-trending, eastward dipping homocline. The strike of the strata is generally N20 to 40W with dips ranging from 20° to 75° eastward.

No major folds were mapped along the West Side Conveyance System and only a few minor folds or wrinkles were observed.

Several zones of major faulting and shearing were outlined during the investigation of the area. These zones are characterized by shearing and brecciation of Cretaceous rock, and offset or truncation of lithologic units. Locally the rock has been reduced to a clayey gouge.

The most prominent zone of faulting is located near the southern end of the System and has been named the Paskenta fault zone. This zone of weakness consists of a series of northwest-trending shears along which the rock has been brecciated and deformed. Although the deformation is intense along individual shears, the rock adjacent is often completely unaffected. Thus, the fault zone contains lenses of fresh unfractured material, bounded by shears.

A second area of major faulting crosses Elder Creek southwest of Galatin damsite (see Plates 29 and 30). This zone also consists of several northwest-trending faults which offset rock units of the Cretaceous. The magnitude and intensity of deformation is considerably below the Paskenta fault zone.

Another major fault was mapped along Sulphur and Guyre Gulches, trending northeast and crossing Cold Fork Creek at Cold Fork damsite. This zone of parallel shears is over one-half mile in width and represents a major zone of weakness. Displacement along this fault was estimated to be over 1 mile, as determined by the displacement of the Knoxville contact. The direction of movement appears to be left lateral.

Foundation Conditions

All but two of all the proposed damsites of the West Side Conveyance System lie at least in part on rock units of the Cretaceous group. The only exceptions are Long Gulch and Red Bank damsites which lie entirely in the Tehama formation.

Foundation conditions in Cretaceous rocks are determined by the rock types, the degree of weathering, and the intensity and direction of shearing and fracturing. The most favorable conditions exist in areas underlain by resistant units such as sandstone or conglomerate. Generally only minor foundation stripping is required in these rock units.

Mudstone and shale is much susceptible to weathering and is generally covered by a mantle of soil and slopewash. Due to relatively light vegetation the depth of soil and colluvium rarely exceeds 5 feet, although accumulations of over 10 feet were noted near the bottom of canyon slopes where material accumulates by downslope creep.

Adverse foundation conditions were observed locally near the Tehama contact. It appears that the Tehama sediments were deposited onto an erosional surface, where rock has been subjected to a long period of weathering. Near the contact, Cretaceous shale and mudstone are often bleached and altered to soft clayey material with very little strength. In other areas the Cretaceous rock at the contact appears to be relatively fresh and does not present any foundation difficulty.

The Tehama formation should be a fair foundation rock for low earthfill structures. Leakage through pervious strata should not be of any consequence due to the discontinuity of lense-shaped Tehama sedimentary units.

Damsites located on major fault or shear zones will require special foundation treatment to prevent foundation failure or excessive seepage.

<u>Construction Materials</u>

Impervious construction materials in the West Side Conveyance System area consist of two types -- soil and slopewash derived from the Cretaceous bedrock and the unconsolidated sediments of the Tehama formation. Locations of the various types of materials are shown on Plate 31, "Location of Construction Materials".

Soil and slopewash is present in a very limited quantity and should not be considered as a source of impervious fill if the Tehama sediments are nearby.

The Tehama sediments consist of unconsolidated flood plain deposited silts, silty clays, clayey gravel, and silty sand. Overall the Tehama sediments appear to be an excellent source of impervious to semipervious fill and are present in sufficient volume for the construction of the proposed earthfill dams.

Samples of the Tehama material have been collected and tested in the Glenn Reservoir area. The character of the material in this area appears to be the same as the Tehama formation material near the West Side Conveyance System.

Pervious materials, suitable for construction of filters and drains as well as concrete aggregate, appear to be in very short supply. Sizeable deposits of stream alluvium are confined to the channels of the Middle Fork Cottonwood, South Fork Cottonwood, Thomes, and Stony Creeks. The total quantity of the local stream alluvium appears to be insufficient for the construction of the proposed projects and will have to be supplemented by material from the Sacramento River channel.

Rockfill sources consist of relatively thin beds and lenses of sandstone and conglomerate. Only two damsites in the West Side Conveyance System have been considered for rockfill dams, due to the scarcity of suitable material.

A vast but questionable source of construction material is the excavated rock from the connecting channels. This material consists predominantly of ripped mudstone and shale and its embankment characteristics are as yet not clearly defined.

The shale and mudstone has a tendency to slake on exposure to air. The initial breakdown into smaller sizes takes place within a relatively short time interval. The further breakdown rate of the slaked chips of rock is apparently more gradual, and less pronounced. Slaking rates of the ripped mudstone-shale material will determine to a great extent its suitability as embankment material in hydraulic structures.

Samples were obtained from some of the proposed channel areas and have undergone extensive testing in the soils laboratory. The suitability of this material as embankment fill is considered questionable on the strength of present knowledge.

In the preliminary cost analysis on the West Side Conveyance System, the ripped mudstone-shale chips were not considered as a source of embankment material. Necessary revision will be made if the mudstone-shale chips will prove out to be suitable in certain sections of the proposed earthfill structures based on future, more detailed analyses.

Methods of Channel Excavation

Open cut channels in the bedrock series are generally located in north- to northwest-trending topographic depressions or saddles. These topographic lows are underlain by softer rock types such as mudstone and shale. The alignments of the channels are thus roughly parallel to the prevailing attitudes of the bedrock units. Several of the excavations will cut across the bedding and will encounter hard, competent rock. Conveyance channels in the Tehama sediments will penetrate unconsolidated flood plain deposits and a bed of pumice tuff.

In the preliminary stages of the West Side Conveyance System investigation, both common as well as hardrock methods of excavation were considered in the mudstone and shale of the bedrock series. Common methods using tractor-mounted rippers and scrapers will be employed in the weathered and jointed upper zone of the rock. This zone of rippable rock was estimated roughly at 80 feet. Below 80 feet the hardrock excavation methods were used in the preliminary cost analysis.

Additional exploration including a comprehensive seismic study, rock testing, and especially test ripping is necessary for a more precise determination of the limits of common excavation.

The rippability of the mudstone and shale below the zone of weathering will be largely determined by the hardness of the rock, the thickness of individual interbeds, and the degree of jointing. The direction of ripping in the thinly laminated, dipping mudstone and shale will be an important factor in extending the limits of common excavation methods. The ripper penetration will vary while traveling in different directions with respect to the bedding. The deepest shank penetration will be realized while ripping normal to the strike and against the dip of the inclined strata. However, ripping against the bedding may result in uprooting of large slabs of rock which may not be handled effectively by scrapers.

Increased ripper production can be obtained in hard rock by using two tractors in a tandem arrangement. Two heavy tractors, equivalent to Caterpillar D-9, together with a heavy duty ripper shank may provide enough power to excavate even the deepest channels underlain by mudstone and shale without the use of blasting.

Extensive experimentation with various ripping techniques must be conducted to determine the most economical method of excavation and to outline the limits of rippable material in the conveyance channels.

Portions of conveyance channels underlain by mudstone, conglomerate, and rock of high sandstone-mudstone ratio are considered to be unrippable except for the uppermost 10 to 15 feet where the rock is intensely weathered and fractured. This rock will be excavated by drilling and blasting and will be removed by shovels and trucks.

Excavation of conveyance channels in the Tehama sediments is expected to be accomplished almost entirely by scrapers with only limited ripping in some of the more consolidated lenses or interbeds. Ripping will be required in the Nomlaki tuff member.

The distribution and the structure of rock units in the open cut channels is illustrated on the regional geologic maps, Plates 28 through 30.

Stability of Slopes

Stability of the side slopes of the proposed open cut conveyance channels is dependent on the depth of the excavation, the intensity of weathering and fracturing of the rock, the degree of consolidation, and on the geologic structure or attitude of the underlying strata.

Virtually all of the channel cuts will lie at least in part in rock units of the bedrock series. Conveyance channels are located in northwest-trending topographic depressions or saddles which are underlain to a great extent by the least resistant rock such as thinly bedded mudstone and shale. Slope stability in the mudstone-shale is controlled by the depth of the weathered zone, the degree of jointing or shearing, and by the direction of strike and dip of the strata with respect to the excavation.

The average depth of weathering in the mudstone and shale varies from 20 to 35 feet. Below this zone weathering is restricted to alteration along major joints.

Side slopes in the weathered mudstone-shale should be stable on a 2:1 slope. In fresh mudstone-shale, the stability of excavated slopes is dependent to a great extent on the direction of the cut with respect to the strike and on the magnitude of the dip.

Nearly all of the channels are roughly parallel to the regional attitude which varies from north-south to N30W with an eastward dip from 30° to 70°. In excavations nearly parallel to the strike, the western or the dip slope will be considerably less stable, due to the possibility of slippage along the inclined bedding planes. The dip slope becomes stable if the angle of the excavation is equal to or less than the angle of the dip.

The excavations in mudstone and shale should be asymmetrical with the dip slope varying from 1:1 to 1-3/4:1 depending on the magnitude of the dip. The opposite eastern slope will generally be stable on 1:1 in fresh unfractured mudstone. Berms should be constructed for every 50 vertical feet to facilitate removal of slaking material and to preclude the danger of sliding.

Cut slopes in the Tehama sediments are expected to stand safely on a $1\frac{1}{2}$:1 to 1-3/4:1 slope. These values were selected in the preliminary analysis, based on soil test results on similar material in the Glenn Reservoir area. It was assumed that the slope will be stable if the slope angle does not exceed the angle of internal friction of the sediments. Preliminary test results gave phi angle magnitudes of 30° to 35°. Berms should be constructed every 50 vertical feet to reduce the danger of sliding and to facilitate periodic maintenance. Excavation slopes in channels less than 50 feet deep are expected to be stable on a 1:1 slope.

In the preliminary cost analyses the conveyance channels in the Tehama formation were left unlined. Additional detailed study may show that fine-grained and loose portions will require lining.

Conclusions

1. The purpose of the engineering geologic study of the proposed West Side Conveyance System was to gather data for a preliminary cost analysis of the entire project. During the course of the investigation a number of alternate plans were considered and interim cost estimates were made. The plan selected for further study appears to be the most economical route of transporting the water into the Glenn Reservoir.

2. Geologic studies of the West Side Conveyance System consisted of reconnaissance reports on the foundation conditions and the availability of construction materials, in addition to a preliminary evaluation of the excavation methods and slope stability of the proposed conveyance channels.

Any further, more detailed geologic work will require better topographic coverage. The only available maps are USGS 7½-minute quadrangles with a scale of 1:62,500 and a contour interval of 50 feet.

3. Foundation conditions for the proposed West Side Conveyance dams were found to be generally sound and no unusual construction difficulties are anticipated.

4. The principal source of construction materials is the unconsolidated flood plain sediments of the Tehama formation, which are located within hauling distance of every proposed damsite. Preliminary soil test results indicate this material to be an excellent source of impervious fill. Pervious materials suitable for filters and drains are in short supply in the Conveyance System area, and may have to be supplemented by the pervious materials from the Sacramento River channel.

5. Both common as well as hardrock methods will be used in excavating the proposed conveyance channels. Common excavation methods will be used in the Tehama sediments and in the weathered and fractured upper zone of the Cretaceous mudstone and shale. Drilling and blasting will be required in sandstone and conglomerate. Test ripping and additional seismic study is required for a proper evaluation of excavation methods of the mudstone-shale below the weathered zone.

In the preliminary planning stages of the investigation, the depth of "rippable" mudstone-shale was estimated to be 80 feet.

6. A preliminary slope stability study of the proposed open cut channels was made and the following conclusions were reached:

Channels in Bedrock (Cretaceous)

a. Virtually all the excavations in the rock types of the bedrock series will be nearly parallel to the formation strike.

b. The western or the dip-slope will be stable if the angle of the cut slope dces not exceed the angle of the dip.

c. The eastern excavation slopes will be generally stable on a 1:1 ratio with benches every 50 vertical feet.

d. Intense weathering and fracturing in the upper 30 feet of the excavation may require a slope as shallow as 2:1.

e. Several conveyance channels cut across fault or shear zones and will encounter intensely brecciated, locally altered rock. Cut slopes in the sheared mudstone and shale will have to be as shallow as 3:1 to alleviate the danger of sliding. Concrete lining will be required in shear and fault zones. Additional geologic mapping and subsurface exploration will be required for a more detailed evaluation of the slope stability problems in sheared and brecciated rock.

Channels in Tehama Sediments

a. Excavation sides in the virtually unconsolidated flood plain sediments will generally be stable on a slope which does not exceed the angle of internal friction of the material.

b. Based on preliminary soil test data the side slopes in the Tehama sediments should stand on a 1-1/2 to 1-3/4:1 slope in cuts deeper than 50 feet.

c. Excavation slopes in cuts less than 50 feet deep should stand on a 1:1 slope.

d. Berms or benches will be required and should be placed every 50 vertical feet.

Recommendations

1. Several alternative conveyance routes on portions of the overall plan which have been considered are shown on Plates 28 to 30. Based on current engineering geologic data, the alternative schemes appear to be more economical and should lower the overall project cost.

The proposed alternative plans are as follows:

a. Alternative Trueblood-Long Gulch channel. This alternative channel will require the excavation of nearly one-half the volume of the original channel.

b. Alternative Long Gulch-Cold Fork channel and a 50-foot-high dam on Red Bank Gulch appear to be more economical than the original plan. Nearly all the excavation of the alternative scheme will be by common methods. Hard sandstone and conglomerate crosses the alignment of the original plan and will require extensive drilling and blasting.

c. The alternative Cold Fork-McCartney channel eliminates Guyre Damsite and appears to be the more economical route. Preliminary geologic data indicate that nearly 75 percent of the original channel is underlain by sandstone and will be removed by hardrock methods. The alternative channel is underlain by the Tehama sediments and Cretaceous mudstone and should be excavated almost entirely by common methods.

d. In the Digger Reservoir group a small saddle dike (alternative to Dike 22) can replace an 80-foot-high dam, sacrificing a relatively insignificant area of storage. The proposed damsite lies on a major shear zone, and considerable construction difficulties can be anticipated. The alternative plan calls for a 60-foot-deep conveyance channel, which should be excavated entirely by common methods.

2. Topographic maps available at the present time can be used only for reconnaissance planning work. Large scale topographic maps are required for any further, more detailed studies of the West Side Conveyance System.

3. Additional geologic mapping of the project features is recommended as soon as better maps become available.

4. Detailed foundation study of some of the more important dam sites in the System should be undertaken. Foundation exploration should include dozer trenches, diamond core drilling, and water pressure testing.

The first damsite recommended for detailed foundation study is Lower Cold Fork damsite. Exploration should consist of diamond drilling in the channel section to determine the intensity and extent of the projected fault zone.

Undisturbed samples of Nomlaki tuff and Tehama sediments should be obtained from the left abutment to determine the suitability of this material in the dam foundation.

5. Test ripping of the Cretaceous mudstone and shale is necessary for a more definite evaluation of excavation methods. Test ripping should be performed in an active stream channel where weathering is at a minimum and where the most difficult ripping conditions will be encountered.

A comprehensive seismic survey should be conducted concurrently with the test ripping.

6. An extensive borrow materials investigation is recommended. The soil test data available at this time are based on the construction materials in the Glenn Reservoir area. Particular emphasis should be placed on determining the suitability of shale and mudstone chips in the proposed earthfill structures.

7. Undisturbed samples of the Tehama sediments should be obtained from a number of the proposed opencut channels. Test results on these samples should give more accurate data for a slope stability analysis and concrete lining requirements.

TABLE 15

WEST SIDE CONVEYANCE SYSTEM
DAMSITE SUMMARY

Damsite	Height of Dam (feet)	Crest Elevation	Type Dam Recommended	Total Volume Fill in Cubic Yds	Foundation Conditions	Average Foundation Stripping in Feet: Impervious RA	Impervious CH	Impervious LA	Pervious RA	Pervious CH	Pervious LA	Spillway Type and Location	Construction Materials Type and Distance from Site in Miles: Impervious	Pervious	Rockfill	Riprap
Fiddlers	266	1,015	Earthfill	6,376,000	Foundation underlain predominantly by mudstone with thin sandstone interbeds and conglomerate beds. Strike is across channel dipping 15° to 25° downstreams. Both abutments are mantled by slopewash and soil and contain two alluvial terraces. No unusual construction problems are anticipated.	15	10	15	5	3	3	Saddle type recommended. About 0.5 mile NW of site. Lining will be required.	3 mi E Tehama Formation	9 mi NE Alluvium Limited volume suitable for filters and drains	None	4½ mi NW Sandstone and conglomerate
Lower Pentacola	235	1,015	Earthfill	5,776,000	Foundation consists of thinly bedded mudstone with interbeds of sandstone. Outcrops of fresh bedrock are found only in the active stream channel. The abutments are underlain by deeply weathered rock which is mantled by soil, slopewash, and alluvial terraces.	10	6	6	7	5	4	Left abutment. Lining required.	1.5 mi NE Tehama Formation	10 mi E Alluvium (filters and drains)	None	1 mi W conglomerate
Little Pentacola	145	1,015	Earthfill	600,000	The site lies in a steep, narrow canyon and is underlain by mudstone and sandstone of Cretaceous age. Outcrops are found only in the channel, with the abutments being covered by shallow colluvium.	5	1	6	4	0.5	5	None	2.5 mi NE Tehama Formation	10 mi E Alluvium (filters and drains)	None	1.5 mi W conglomerate
Meadow Gulch	135	1,010	Earthfill	719,000	The site is underlain by deeply weathered Cretaceous mudstone, sandstone, and conglomerate. Outcrops confined to stream channel. Site located in a steep, narrow canyon.	5	3	6	4	1	4	None	2.5 mi SW Tehama Formation	15 mi E Alluvium (filters and drains)	None	1 mi W conglomerate
Upper Pentacola	150	1,010	Earthfill	1,143,000	The site foundation consists of deeply weathered shale-mudstone with thin sandstone interbeds. Deep colluvium covers the abutments. A shallow bench terrace was mapped on both abutments about 50 feet above streambed. This bench has been subsequently filled by soil and slopewash from adjacent slopes.	15	10	15	10	8	10	Left abutment. Lining required owing to deeply weathered rock.	2 mi NE Tehama Formation	10 mi E Alluvium (filters and drains)	None	2 mi W Limited volume of conglomerate

TABLE 15 (Continued)

WEST SIDE CONVEYANCE SYSTEM
DAMSITE SUMMARY

Damsite	Height of Dam (feet)	Crest Elevation	Type Dam Recommended	Total Volume Fill in Cubic Yds	Foundation Conditions	Average Foundation Stripping in Feet: Impervious RA	Impervious CH	Impervious LA	Pervious RA	Pervious CH	Pervious LA	Spillway Type and Location	Construction Materials Type and Distance from Site in Miles: Impervious	Pervious	Rockfill	Riprap
Saunders	233	1,008	Earthfill	6,211,000	The site lies in a steep canyon cut by Salt Creek through interbedded sandstone and mudstone of the Shasta-Chico series. The approximate sandstone-mudstone ratio was estimated at 40:60. Outcrops are confined to the active channel. The upper abutments are covered by a mantle of soil and slopewash with extensive evidence of soil creep. The strike of the strata is N15W - normal to the stream channel, dipping 25° downstream.	15	8	15	7	2	7	Either abutment. Also a saddle spillway should be considered.	2 mi SE Tehama Formation	5 mi E&W Tehama Formation	None	0.05 mi W conglomerate
Trueblood I	75	1,005	Earthfill	)	The four sites are underlain by Cretaceous mudstone and sandstone.	6	7	7	4	5	5	None	1 mi E Tehama Formation	10 Mi SE Alluvium for filters and drains	None	1 to 2 mi conglomerate and sandstone
Trueblood II	135	1,005	Earthfill	) 888,000		5	1	5	3	1	3					
Trueblood III	75	1,005	Earthfill	)		5	1	5	3	1	3					
Trueblood IV	75	1,005	Earthfill	)		7	3	3	4	2	3					
Long Gulch	80	1,005	Earthfill	720,000	The site lies in a wide canyon underlain by poorly consolidated sediments of the Tehama formation. The sediments are dipping 3° - 5° to the east and consist of silty-gravelly clay. The Nomlaki tuff lies about 20 feet below the channel.	5	10	5	3	6	3	None	At Site Tehama	3 to 5 mi E Alluvium (filters and drains)	None	3 mi S Sandstone
Red Bank	50	1,005	Earthfill	300,000	Foundation material consists of Tehama gravelly clays and silts. (Very similar to Long Gulch damsite.)	7	9	5	5	4	3	None	At Site Tehama	5 mi E Alluvium for filters and drains	None	3 mi S Sandstone
Lower Cold Fork	165	1,005	Earthfill	2,282,000	The site is underlain by both Tehama sediments and Cretaceous sandstone and mudstone. Major fault zone was projected into the channel.	10	12	10	6	10	5	None	0.25 mi E Tehama from Cold Fork-McCartney Channel.	4 mi E Alluvium suitable for filters & drains	Potential sandstone quar4y located about 1 mi SE from site	1 mi SE Sandstone
Guyre	153	1,003	Rockfill	720,000	Site lies in a steep narrow canyon underlain by hard stratified Cretaceous sandstone.	3	2	4	2	2	3	None	0.25 mi E Tehama	3 mi NE Alluvium for filters & drains	1 mi W & SE sandstone	1 mi W & SE

TABLE 15 (Continued)

WEST SIDE CONVEYANCE SYSTEM
DAMSITE .

Damsite	Height of Dam (feet)	Crest Elevation	Type Dam Recommended	Total Volume Fill in Cubic Yds	Foundation Conditions	Average Foundation Stripping in Feet: Impervious RA	Impervious CH	Impervious LA	Pervious RA	Pervious CH	Pervious LA	Spillway Type and Location	Construction Materials Type and Distance from Site in Miles: Impervious	Pervious	Rockfill	Riprap
McCartney	211	1,001	Earthfill	2,200,000	The site is situated in a steep canyon cut through sandstone and shale of the Shasta-Chico series. The upper abutments are covered by silty-clayey gravel of the Tehama formation.	5	6	8	3	4	5	Left abutment	0.5 mi E Tehama Formation	3 mi E & W Alluvium for drains and filters	None	1 mi W Sandstone
						(Stripping depth will be extremely variable)										
Bluedoor	195	995	Earthfill	2,141,000	The channel and the lower abutments are underlain by weathered Cretaceous sandstone and mudstone. The uppermost abutments are in Tehama sediments. Very poor foundation rock is anticipated at the contact.	8	10	8	5	7	6	None	0.25 mi E Tehama Formation	5 mi NE Alluvium (filters & drains)	None	2.5 mi NW
Schoenfield	258	998	Rockfill	2,667,000	The proposed damsite is located in a narrow gorge cut by the stream through sandstone of the Shasta-Chico series. The rock consists of a hard stratified sandstone with occasional thin mudstone interbeds. Outcrops are found over 75 pereent of the abutment slopes.	4	3	4	2	2	2	Saddle spillway in hard sandstone	1 mi E Tehama Formation	3 mi E Alluvium (filters & drains)	1 mi SE Sandstone	1 mi SE Sandstone
Galatin	262	982	Earthfill	4,416,000	Rock types at the site consist primarily of conglomerate and sandstone with minor amounts of mudstone. The strike is N15E, dipping 25 - 30° eastward.	5	3	8	3	3	4	Saddle spillway; cut will be in conglomerate salvagable for riprap	1 mi SE Tehama	5 mi E & W Alluvium for filters & drains	None	0.5 mi SE conglomerate
Lower Cat Ridge (Dike 21)	150	978	Earthfill	Not estimated	Lower Cat Ridge damsite consists of one 100-foot dike and an adjacent 25-foot saddle dike. The site lies in an area of moderate topographic relief and is underlain by shale-mudstone of the Knoxville formation. The strata is northsouth, dipping 40 to 65° E. A major northwest trending shear zone was mapped in a short distance west of the proposed site. No shearing or faulting was noted in the foundation of the main damsite, however, the fault zone passes through the saddle dike. Outcrops are confined to the channel with the abutments mantled by about 4 feet of soil.	5	4	3	3	3	2	None	2 mi slopewash terrace materials within 2 mi radius	5 mi E Alluvium	None	0.5 mi W Sandstone
Upper Digger	85	977	Earthfill	Not estimated	Site underlain by shale-mudstone (80%) with thin sandstone interbeds (20%). Shallow soil and colluvium mantle abutments.	7	6	7	5	5	5	None	7 mi E Tehama	3 mi SE Alluvium	None	1 mi W Sandstone

TABLE 16

WEST SIDE CONVEYANCE SYSTEM
SUMMARY OF CHANNELS

Channel	Length in Feet	Maximum Depth in Feet	Total Volume in Cubic Yds. (estimated)	Estimated Percent of Common Excavation	Geologic Conditions	Average West	Slope East	Remarks
Fiddlers-Pentacola	6,000	170	6,299,000	60%	The proposed open cut channel is underlain by thinly bedded black mudstone, with occasional sandstone interbeds. Outcrops are scarce because of a steep mantle of soil. The strike is about N-S with a dip from 35 to 25° east. Cut is nearly parallel to strike.	1-3/4:1	1:1	
Lower Pentacola-Little Pentacola	1,000	150	1,000,000	40%	Same as Fiddlers-Pentacola	1-1/2:1	1:1	)Alternate to Upper)Pentacola-Saunders Channel.)
Little Pentacola-Meadow Gulch	4,200	250	8,874,000	40%	Same as Fiddlers-Pentacola	1-1/2:1	1:1	)))
Meadow Gulch-Saunders	3,000	230	4,205,000	40%	Same as Fiddlers-Pentacola	1-1/2:1	1:1	)
Upper Pentacola-Saunders	17,000	293	36,653,000	50%	Channel lies in a north-south trending saddle bounded to the east and west by ridges of more resistant rock. The dominant rock type underlying the saddle is thinly bedded mudstone with occasional sandstone interbeds. The attitude of the strata is north-south dipping 25 to 35° to the east. Near the Northern and southern limits the channel excavation would penetrate two resistant units, containing at least 25 percent of sandstone (see Plate ___).	1-1/2:1	1:1	
Saunders-Trueblood	1,100	220	5,940,000	50%	The channel is underlain by Cretaceous mudstone and shale with occasional thin sandstone interbeds. The average thickness of the mudstone strata is 2-3 in. The strike is N5 to 10W with a dip of 20 to 30°E.	1:1	1:1	
Trueblood-Long Gulch	3,500	245	1,939,000	90%	About 80 percent of the excavation will be in Tehama sediments with the remainder in deeply weathered Cretaceous mudstone. Unstable rock is anticipated at the contact.	1-3/4:1	1-3/4:1	This channel is not recommended in this report.

Channel	Length in Feet	Maximum Depth in Feet	Total Volume in Cubic Yds. (estimated)	Estimated Percent of Common Excavation	Geologic Conditions	Average West	Slope East	Remarks
Alternate Trueblood-Long Gulch	4,300	100	900,000	90%	This alternate conveyance channel lies entirely in Cretaceous mudstone-shale. The attitude of the strata is N15W dipping 40-45°E.	1-1/2:1	1-1/2:1	This plan has less volume of excavation and better foundation conditions.
Long Gulch-Cold Fork	8,100	175	15,000,000	80%	The following distribution of rock types were mapped along the proposed cut — Tehama 35%; Nomelaki tuff 25%; mudstone, shale and sandstone 40%.	1-3/4:1	1-1/2:1	Alternate route through Redbank damsite may be more economical.
Alternate Long Gulch-Cold Fork	7,900	175	13,000,000	100%	The alternate channel is underlain entirely by Tehama sediments. This plan will require a 50-foot high dam in Redbank Creek.	1-3/4:1	1-3/4:1	Saving in volume may be offset by lining of the canal.
Cold Fork-McCartney via Guyre	13,000	290	15,000,000	25%	The cut will be in Tehama sediments (20%) and in hard Cretaceous sandstone (80%). The attitude of the sandstone is N45W dipping 40E.	1:1	3/4:1	75 percent of hardrock excavation makes this route economically questionable.
Alternate Cold Fork-McCartney	11,000	270	20,000,000	95%	The following proportions of rock types were mapped in the proposed channel: Tehama sediments including Nomelaki tuff 35%; Cretaceous mudstone-shale 65%. The attitude of the bedrock units is N45W dipping 40°E. The mudstone may be intensely weathered near the channel invert and may require lining.	1-1/2:1	1-1/2:1	Extensive subsurface exploration required to determine the rock conditions near the channel invert.
McCartney-Bluedoor	5,200	160	6,800,000	60%	Channel underlain by thinly bedded Cretaceous mudstone-shale. The rock is deeply weathered and some shearing was noted locally. The alignment of the cut is nearly parallel to the strike of the strata.	1-1/2:1	1:1	Exploration needed to determine the condition of the rock.
Bluedoor-Schoenfield	1,000	115	1,900,000	95%	Rock types consist of deeply weathered thinly bedded mudstone and shale. The channel is nearly parallel to the strike. The strata - N10W dipping 50E.	1-3/4:1	1:1	

Sheet 2 of 4

TABLE 16
(continued)

Channel	Length in Feet	Maximum Depth in Feet	Total Volume in Cubic Yds. (estimated)	Estimated Percent Of Common Excavation	Geologic Conditions	Average West	Slope East	Remarks
Schoenfield-Galatin	12,700	250	16,500,000	50%	The northern portion of the channel is underlain by thinly bedded black mudstone and shale bounded to the east and west by ridges of more resistant rock. The attitude of the bedding is nearly north-south with an eastward dip of 40 to 45°. Soil and slopewash mantle the cut area making precise determination of the structure difficult. Intense shearing and fracturing was observed near the northern end of the proposed channel indicating a fault zone. The magnitude and the fault zone and the direction of displacement were not determined. The direction of shearing appears to be to the northeast. The southern portion of the excavation lies in a narrow canyon underlain by a sequence of hard and resistant conglomerate and sandstone (see Plate ___). The direction of the cut is normal to the strike.	1-3/4:1	1:1	
Galatin-Lower Cat Ridge	17,500	205	29,600,000	65%	The open cut channel lies in a north-south trending topographic depression, bounded to the east and west by ridges of more resistant rock. The channel is underlain by thinly bedded mudstone with occasional sandstone lenses and interbeds. A zone of higher sandstone-mudstone ratio was mapped near the center of the topographic depression, averaging about 15 percent. The bearing of the cut is roughly north-south, nearly parallel to the bedding. The strike of the strata averages about N5 to 10E with a dip of 50 to 65° to the southeast. No faults or shear zones were mapped in the channel area. Locally bedrock is mantled by slopewash which has a maximum thickness of 10 feet but does not average more than about 5 feet.	1:1	1:1	

(continued)

Channel	Length in Feet	Maximum Depth in Feet	Total Volume in Cubic Yds. (estimated)	Estimated Percent Of Common Excavation	Geologic Conditions	Average Slope West	Average Slope East	Remarks
Cat Ridge–Digger–Paskenta	9,100	170	10,158,000	75%	The entire cut is underlain by thinly bedded shale and mudstone of the Knoxville formation. The attitude of the strata in the southern one-half of the cut is about N40E, dipping 60° to the southwest. In the northern portion of the cut considerable faulting and shearing was observed and the attitudes are very inconsistent. This sheared zone will affect one-half of the excavation, with the maximum depth of cut being nearly 100 feet. The average depth should be about 50 feet. The direction of faulting is N40W, nearly normal to the centerline of the excavation.	1-3/4:1	1-1/2:1	

TABLE 17

GEOLOGIC CHARACTERISTICS OF DAMSITES

Trinity River and Clear Creek

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
Sec.10,T8N, R4E,HB&M	Beaver	Trinity River	Chiefly thinly laminated chlorite schists, phyllites, and related rocks, all having imperfect slaty cleavage. Often talcose or micaceous. Weathered rock is punky and easily broken by hand. Major shears or faults are present, as exposed in mine tunnel in east canyon wall. Rock hard and compact where fresh in channel bottom. Much quartz veining. Mineralization along shear zones. Joints moderately developed.	Light overburden stripping on both abutments is indicated and there is only a little gravel in channel section. Rock stripping would be only moderate, considering the great height of dam proposed here.	Steep side slopes permissible on cut. Good rock under shallow depth of soil in area of weir. Only part of the complete spillway section should need lining.		I-Some suitable material probably available at north end of Hoopa Valley. P-Very limited amounts of gravel in Hoopa Valley. Also spoils and quarry rock. RF & RR-Plentiful supply from spoils and by opening quarries locally in bedrock. Aggregate-Limited amounts of gravel and sand along river channel, especially in Hoopa Valley. Might have to manufacture or import large quantities.	Moderate	Fill type dam	Much special treatment of fault zones including dental work, etc. might be necessary. Thorough exploration of entire site and especially of these zones is needed. Moderate to heavy grouting expected.
Sec.36,T8N, R4E,HB&M	Hoopa	Trinity River	<u>Right Abutment</u> -- The right abutment is covered by recent river terrace material composed of sand, gravel and boulders. <u>Channel Section</u> -- The river channel area is composed of loose sands and gravels. <u>Left Abutment</u> -- The foundation rock exposed on the left abutment is severely crushed shale of the Jurassic Galice formation.	Estimated for a low concrete dam. <u>Right Abutment</u> -- Strip 15' of terrace gravels and 20' of fractured rock. <u>Channel Section</u> -- Strip 20' of sand and gravel and 10' of fractured rock. <u>Left Abutment</u> -- Strip 20' of fractured rock.			Aggregate-For a concrete structure may be obtained from river gravels along the Trinity River.	Moderate	Low concrete or fill dam.	
Sec.5,T7N, R5E,HB&M	Horse Linto	Trinity River	The site is underlain by hard, massive metasediments. Bedding strikes parallel to the river channel and dips into the right abutment. Joints are present and are fairly tight.	Estimated for a concrete dam. <u>Abutments</u> -- The lower portions of the abutments will require 20' of stripping of jointed rock. The upper portions of the abutments will require stripping of 2' of soil and 40' of weathered and jointed rock. <u>Channel Section</u> -- Strip 10' of channel fill and 2' of jointed bedrock to shape.	If an overpour spillway is utilized on a concrete dam, protection of the plunge pool will be necessary.	Tunneling conditions should be good with only a moderate amount of overbreak.	RF-May be quarried from metasediments near the site. Aggregate-For a concrete structure may be obtained from deposits of river gravels along the Trinity River.	Moderate	Rockfill dam. Concrete dam.	

TABLE 17 (continued)

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
Trinity County	Beartooth	New River	The site is underlain by deeply weathered hornblende diorite and biotite granodiorite of the Ironside Mt. batholith. A steep inner gorge up to 75' deep exposes bare, jointed rock with minor shearing.	Estimated for a fill dam 250' high. Right Abutment -- Impervious section: Strip 40'-50' of slopewash and weathered and fractured rock. Pervious section: Strip 10'-15' of decomposed rock and slopewash. Channel Section -- Impervious section: Strip 10'-20' of fresh, jointed rock for shaping. Pervious section: Strip 1'-3' for shaping. Left Abutment -- Impervious section: Strip 40'-50' of weathered and fractured rock. Pervious section: Strip 10'-15' of decomposed rock and slopewash.	An around the end type spillway is recommended on the left abutment.		No construction materials were located near the site or in the reservoir during a brief reconnaissance. Further exploration for borrow areas is needed.	Moderate		
SW 1/4 Sec.35, T6N,R6E,HB&M	Ironside	Trinity River	Right Abutment -- The right abutment is underlain by massive, jointed meta-andesite. A schistose zone of structural weakness, possibly a fault, occurs on the abutment. Minor shear zones are present. Channel Section -- The channel is approximately 40' wide. Bedrock is exposed and channel fill consists of boulders. Left Abutment -- The left abutment is underlain by massive, jointed meta-andesite. A large outcrop of serpentine occurs downstream and may be continuous through the abutment. The major joint set strikes parallel to the stream and dips toward the channel.	Estimated for a masonry type structure. Right Abutment -- Strip 1' - 3' loose rock and soil mantle plus 8' - 12' jointed rock. Channel Section -- Remove 5' average of boulders and strip 2' of massive rock to shape. Left Abutment -- Strip 1' of loose rock and gravel by washing and 12' of jointed and weathered bedrock.		Tunneling through the hard meta-volcanic rocks will be expensive. Water cannot feasibly be moved downstream except by tunnel.	I-Limited supply of Weaverville sediments near site. P-Channel deposits 4 mi. upstream. RF & RR-Rock at the site could be used.	Low	Earthfill. Rockfill.	

TABLE 17 (continued)

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
Sec.31,T31N, R5W,MDB&M	Seltzer	Clear Creek	Right Abutment -- Hard, fine grained, roughly schistose metavolcanic rock with pronounced jointing is overlain by poorly consolidated Red Bluff gravels. Channel Section -- Hard, fine grained metavolcanic rock is exposed over nearly all the channel section. There are two main sets of joints. One strikes oblique to the channel and dips vertically. The second set strikes roughly parallel to the channel and dips into the left abutment. Left Abutment -- Same as the right abutment. A weathered zone exists in metavolcanic rock at the base of the Red Bluff gravels.	Estimated for an earthfill dam 200' high. Right Abutment -- Impervious section: Below elevation 600; up to 30' of Red Bluff gravels and 10 - 15' of jointed metavolcanic rock. Above elevation 600; 25 - 30' of Red Bluff gravels. Pervious section: 10' of soil and weathered Red Bluff gravels. Channel Section -- Fill stripping: 5' average of sand and gravel. Bedrock stripping: Impervious section: 7' maximum of fractured metavolcanic rock for shaping. Pervious section: 1' - 2' for shaping. Left Abutment -- Impervious section: 25' - 30' of Red Bluff gravels and 10' - 15' of weathered metavolcanic rocks. Pervious section: 10' of Red Bluff gravels. Cutoff section: Stripping should penetrate beneath the weathered zone of metavolcanic rock.	A spillway is recommended around the end of the right abutment. The spillway should terminate in a flip bucket and will require lining in the Red Bluff gravels.		I-Red Bluff clayey gravels and spoils from the spillway and foundation excavations are available at the site. P-Dredger tailings are available from 1/2 to 4 mi. upstream and downstream. RF & RR-May be quarried from granite or Cretaceous sandstone approximately 1 mi. upstream.	Low	Earthfill. Earthfill and rockfill.	

TABLE 17 (continued)

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
T32N,R6W, MDB&M	Towerhouse	Clear Creek	The site is underlain by hard, fine grained metavolcanic rocks. The rocks are moderately jointed with minor shearing and are deeply weathered on the upper abutments. An old river channel is present low on the right abutment.	Estimated for an earthfill dam 300' high. Right Abutment -- Impervious section: 25' - 30' common excavation, 5' hardrock excavation. Channel Section -- Impervious section: 5' of channel gravels. Left Abutment -- Impervious section: 5' low on the abutment. 20' common excavation, 5' hardrock on upper abutment.	An around the end type spillway is recommended on the left abutment. Protection will be required where the cut is in weathered rock.	The left abutment is recommended for a tunnel location.	I-Weathered metavolcanics on slopes and ridges within 2 - 3 mi. of the site are available. P-Dredger tailings 1 mi. upstream from the site may require processing to eliminate unsound material. RF & RR-Metavolcanics may be quarried near the site.	Low	Earthfill, combination earthfill and rockfill.	
T31N,R6W, MDB&M	Kanaka	Clear Creek	The site is underlain by hard, fine grained metavolcanic rock of the Copley formation. This rock is roughly foliated. Pronounced joints strike obliquely to the channel and dip vertically. Another set of joints strikes parallel to the channel and dips into the left abutment.	Estimated for an earthfill dam 250' high. Right Abutment -- Impervious section: 10' - 15' of jointed bedrock and soil. Cutoff: 15' bedrock and soil. Pervious section: 7' bedrock and soil. Channel Section -- Fill stripping - 10' sandy gravel and boulders. Bedrock stripping - Impervious section: 15' of bedrock. Pervious section: shaping only, average 2' of bedrock. Left Abutment -- Impervious section: 7' of fractured rock and soil. Cutoff: 15' of fractured rock and soil. Pervious section: 5' of fractured rock and soil.	An around the end type spillway is recommended through a saddle on the right abutment. Light lining will be required.	A diversion tunnel is proposed through the right abutment.	I-Red Bluff clayey gravels are located 1/2 mi. to the southwest. P-Dredger tailings are located 6 - 11 mi. downstream. RF & RR-May be quarried at the site.	Low	Earthfill and combination earthfill and rockfill.	Location of ample pervious and impervious materials within easy hauling distance is desirable.

TABLE 17 (continued)

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
Sec.26,T31N, R5W,MDB&M	Girvan	Clear Creek	The site is underlain throughout most of its length by dredger tailings about 25' deep. The ends of the fill rest on Red Bluff and Tehama formation clayey gravels. Alluvium underlies the channel section and part of the left abutment.	Estimated for an earth dam with gravel shell 40' high. Right Abutment -- Cutoff trench: 5' colluvium plus 20' of clayey gravel. Transition: 5' colluvium plus 10' of clayey gravel. Select cobbles: 5' colluvium plus 5' - 7' of clayey gravel. Impervious blanket: 5' colluvium plus 5' - 7' of clayey gravels. Channel Section -- Channel fill stripping: 15' - 25' alluvium. Bedrock stripping: Cutoff trench: 20' of gravel, silty clay. Transition: 10' of gravel, silty clay. Select cobbles: 5' - 7' of gravel, silty clay. Left Abutment -- Cutoff trench: 20' - 30' of dredger tailings, 15' of alluvium, 20' of gravel, silty clay. Transition: 20' - 30' dredger tailings 15' alluvium, 10' of gravel, silty clay. Select cobbles: Strip all organic matter from ponds and lake and level irregularities in mounds of tailings. 100% common excavation is probable.	The spillway is of the gated type located downstream from the right abutment and connected to the reservoir by an excavated channel around the abutment.	Outlet works, including a 4' diameter concrete pipe approximately following the stream channel beneath the dam, will be used for diversion.	I-Local Red Bluff and Tehama formation sediments are suitable. P-Local dredger tailings are suitable. RR-3-1/2 mi. upstream at Copley meta-andesite outcrop.	Low	Earth and gravel shell.	1. The possibility of leakage through the right abutment may necessitate an impervious blanket on the abutment slope. 2. A row of relief wells is recommended downstream.

TABLE 18

GEOLOGIC CHARACTERISTICS OF NEW RIVER TUNNEL

Trinity River

Location	Tunnel data	Formations and rock types encountered	Rock conditions	Rock loadfactors (feet)	Percent of tunnel length	Excavation	Overbreak	Support	Water	Seismicity
Trinity County T5-6N,R7E	Diameter -- 12'. Length -- 8.3 mi. Connected Reservoirs -- Beartooth Reservoir to Burnt Ranch Reservoir. Maximum Depth of Cover -- 2,900'.	Ironside Mt. Batholith: Hornblende diorite and biotite granodiorite.	Hard, intact to massive, moderately jointed rock.	0-0.25 B	18	100 percent hard rock. Full face excavation.	Minimum to low overbreak along intersections of joint planes.	Steel ribs on 6' centers. Rock bolts where necessary.	High water inflows are expected to occur in shears and closely jointed zones.	Moderately low.
		Pre-Cretaceous metamorphic rocks: Phyllite, metachert, metavolcanics and limestone.	Massive, moderately jointed to very blocky and seamy rock.	0.25 B - 0.35 (B + Ht)	82	100 percent hard rock. Full face excavation.	Low overbreak along intersection of joint planes, to high overbreak in severely foliated, jointed meta-sediments.	Steel ribs on 4'-6' centers. Rock bolts where necessary.	Hazardous water inflows should be confined to zones of closely spaced interconnected joints or to shears containing permeable crushed material, under considerable depth of cover.	Moderately low.

CHAPTER VI. SOUTH FORK TRINITY RIVER PROJECTS

The featured projects on the South Fork Trinity River, as shown on Plate 1, include Eltapom Dam and War Cry and Eltapom Tunnels as a key feature. These projects are being considered as a second stage of the Trinity River Development. Engineering geology of Eltapom damsite, War Cry Tunnel, and Eltapom (to Helena) Tunnel is discussed in this Chapter. In addition, the geology of one other alternative tunnel route from Eltapom Reservoir to Big Bar Reservoir is discussed in detail. Geologic maps, cross sections, and construction materials location data for most of these projects appear on Plates 32 to 34.

Reconnaissance geologic studies were made on two damsites on the South Fork Trinity River. These data, on Grouse Creek and Grel damsites, are presented in Table 21.

Eltapom Damsite

Eltapom damsite is located in the western part of Trinity County about 30 road miles northwest of Hayfork. The axis of the dam investigated during this reconnaissance study lies in the NE and NW 1/4 of Sections 9 and 10 respectively, T3N, R6E, HB&M. The site is easily reached by an unimproved county road which passes across the lower left abutment.

Previous Work

Previous geologic work in the Eltapom damsite area was concentrated about 1,500 feet downstream from the present axis, where a lower earth-fill structure (420 feet) was explored during the early stages of the North Coastal Area Investigation. This site will be referred to in this report as middle Eltapom damsite. The foundation conditions and availability of materials of middle Eltapom damsite were explored by diamond drilling and dozer trenches during the period November 1956 to February 1957. This middle Eltapom axis was abandoned when it appeared that the upper axis offered better abutment conditions. Therefore, the upper axis, with which this report is concerned, was studied.

Description of Project

The Eltapom Dam would be the second stage development project of the Trinity River Development scheme. In the original plan, water from the Eltapom Reservoir would be diverted through the 13-mile-long Eltapom-Helena Tunnel into the Helena Reservoir and then through the Clear Creek Number 2 Tunnel on the Cottonwood Tunnel into the Sacramento River drainage.

The highest dam proposed for cost estimating purposes has a crest elevation of 1,920, resulting in a 720-foot-high earth, gravel, and rock structure. The reservoir capacity of Eltapom Reservoir at a normal water surface elevation of 1,900 would be 3,100,000 acre-feet.

An uncontrolled chute spillway will be located above the right abutment and will discharge into Eltapom Creek which enters the South Fork Trinity River nearly at the downstream toe of the proposed dam. A narrow nose of rock at the mouth of Eltapom Creek will be removed and the channel widened to provide unrestricted flow away from the toe of the dam.

Location of the axis, spillway, and the outline of the area covered by the embankment is shown on Plate 32, "Geologic Map and Sections, Eltapom Damsite".

Geology of the Site

The proposed Eltapom damsite lies in the Klamath Mountains geomorphic province and is underlain by Chanchelulla formation rock units of Paleozoic to Triassic age. The foundation rock consists primarily of altered basic intrusive and extrusive igneous rock with relatively minor interbeds of slaty metasedimentary rock. Outcrops in the foundation area are generally spotty except for the downstream portion of the right abutment which is underlain by massive meta-volcanic rock.

Two major faults were mapped in the dam foundation area, as shown on Plate 32, and constitute a serious foundation defect. The fault zones are characterized by intensely sheared and brecciated rock and contain lenses of crushed serpentine. The exact width of these zones of weakness is not known owing to a deep colluvial cover and lack of outcrops; however, one fault zone appears to be at least 200 feet wide near the stream channel. The site is extremely complex structurally and will require detailed geologic mapping and a comprehensive exploration program for a proper evaluation of the foundation conditions for the proposed high fill dam.

The channel section is covered by alluvium to a known depth of 70 feet, as determined by core drilling at the lower site. This unusually thick deposit of sand and gravel is the result of partial damming of the river by a large slide located about three-fourths mile downstream from the toe of the proposed dam. The slide has left many large resistant boulders in the stream channel which act as energy dissipators and are retarding the rate of erosion of the river channel.

An alternate lower site is indicated on Plate 32 downstream from Eltapom Creek. This site should be investigated to determine if the projected fault zone which is shown crossing the left abutment and the channel may actually be located above the crest elevation. The present location of the fault is based on slide debris and slumped exposures and may not be representative of the underlying foundation material. The construction of a dam at this location will require the removal of a very large slide known as Big Slide downstream from the left abutment to preclude any possibility of sliding into the embankment section.

Several large landslides were mapped in the reservoir area. The most extensive slide lies at the head of the Hyampom Valley near the confluence of Hayfork Creek and South Fork Trinity River. During the operation of the reservoir or during a major earthquake tremor such slides may become active and could create seiche waves which may endanger the dam embankment. Sufficient freeboard should be provided to prevent overtopping of the dam by landslide-produced tidal waves.

Foundation Conditions

Right Abutment. The right abutment is cut by a major fault which strikes about N35W and passes under the axis at the base of the right abutment and continues into the upstream portion of the abutment slope (see Plate 32). The fault zone does not crop out except for a few isolated, possibly slumped patches of gouge near the stream channel. The topography in the fault area is characterized by a subdued, irregular slope with numerous small benches and breaks in slope indicating old landsliding. Recent sliding was noted although it appears to be minor. Numerous springs and seeps were observed in the deep colluvium which is mantling the fault, and the entire area appears to have a shallow water table.

The average depth of the deep colluvium, as outlined on Plate 32, is probably on the order of 30 feet with a conceivable maximum of up to 50 feet. No exploration was done in this portion of the abutment and all estimates are based on surficial observations. The underlying fault zone is probably similar to the material encountered in four dozer trenches on the left abutment, and consists of crushed and brecciated meta-volcanic rock with zones of gouge and serpentine. A large body of sheared serpentine was mapped in a saddle southeast from the site along the extension of the fault zone and may continue under the colluvium into the dam foundation.

The remainder of the abutment up- and downstream from the deep colluvium is underlain by meta-volcanic rock which should not present any difficulties during construction. The rock is generally a massive to slightly foliated meta-andesite with relatively thin interbeds or lenses of slate and occasional inclusions of massive crystalline limestone. In the upstream toe portion of the right abutment outcrops of rock are spotty and are surrounded by shallow soil and colluvium. The downstream toe area shows nearly continuous outcrops of massive meta-volcanic rock with minor accumulations of slopewash and talus near the base of the slope.

The following three major joint sets are evident in addition to random surficial fracturing: (1) strike N40W to N45W dipping about 80° west to vertical, (2) strike N80E to east and a dip of 55° to 65° south, and (3) strike N30E to N40E dipping westward 45° to 60°.

Based on two drill holes at the downstream axis, the joints are open to a depth of 40 feet normal to the slope and show considerable iron oxide staining but contain no gouge or clay filling. Water losses during pressure testing were moderate to light and grout takes in the cutoff sections should not be excessive in meta-volcanic rock. Grout takes in fault zone material are expected to be highly variable ranging from very high in brecciated rock to low in gougy material.

Foundation preparation of the right abutment for a high dam will consist of the following:

1. Removal of the entire slopewash deposit as outlined on Plate . The average depth of this material is estimated at 30 feet. Stripping of this material above the fill section will eliminate the possibility of landsliding during the operation of the reservoir.

2. The exposed fault zone should be overexcavated to an additional depth of at least 50 feet and backfilled with mass concrete and impervious fill in the impervious section and possibly by selected rock under the rockfill sections. Extensive exploration is required to determine the dimensions, attitude, and foundation conditions of the fault zone. Cut slopes will be in the adjacent meta-volcanic rock which will be intensely fractured near a major zone of weakness. Side slopes should stand on 1-1/2:1 during construction.

3. In addition to the special treatment of the problem area described above, the remainder of the abutment will require the removal of all colluvium and loose weathered rock under the entire dam section -- an average depth of 10 feet. Under the impervious section the weathered and jointed rock should be excavated an additional 5 feet -- an average total of 15 feet. Some minor faults and deeply weathered slate lenses will require special treatment.

Channel. The channel section averages about 300 feet in width and is entirely covered by stream alluvium. The maximum known depth of alluvium is 70 feet as measured in a drill hole at the downstream toe of the dam. The average depth over the entire section is estimated to be 50 feet. The fill material is predominantly clean gravel and sand with lenses of fine material near the periphery of the channel. On the left side of the channel an alluvial deposit which consists of brownish to gray sandy silt was mapped. Three trenches were excavated at this location (see Plate 32), and the material was found to be at least 20 feet deep.

The alluvium is underlain by slate and meta-volcanic rock similar to the rock on the right abutment. Exploration of the channel at the downstream axis consisted of five diamond drill holes which are located at the downstream toe of the dam considered for this plan (see Plate 32). The exploration of the channel section can be considered to be only partially complete and additional drilling is required to cross-drill the areas shown on Plate 32 which lack exploration.

The bedrock underlying the channel in the downstream toe area is only surficially weathered -- the intensely weathered zone varied from 0 to 9 feet in the five drill holes.

A major fault crosses the channel under the alluvium near the axis of the proposed dam. The fault zone is estimated to be about 200 feet wide and consists of sheared to completely crushed and partially serpentinized meta-volcanic rock -- as interpolated from dozer trenches on the left abutment.

Another, somewhat narrower fault zone parallels the channel on the lower left abutment and may dip under the channel gravels near the upstream toe of the proposed dam. This fault zone appears to contain similar material as encountered in the four trenches on the left abutment. An extensive exploration program is required to determine the exact location and extent of the fault zones.

Foundation preparations in the channel section will require the following work:

1. Removal of all unconsolidated alluvium from the entire foundation of the dam. The average depth of material is 50 feet with a conceivable maximum of 80 feet. Seepage into the excavation could be effectively controlled by continuous bored concrete pile diaphragms and by alluvial grouting.

2. The major fault zones should be overexcavated to a depth of at least 50 feet and backfilled with concrete and/or selected fill material. It should be noted that the fault crosses the channel almost entirely under the impervious section. The extent of the excavation will be greatly determined by the attitude and dimensions of the zone of weakness.

3. The remainder of the channel section below the alluvium should be stripped an average of 10 feet under the impervious section and 5 feet under the transitional and rockfill sections. Minor faults or deeply weathered or altered interbeds of weak rock should be over-excavated and backfilled with suitable material.

Left Abutment. The left abutment is underlain almost entirely by meta-volcanic rock except for the downstream toe which is underlain by slate, schist, and hornfels.

The lower 100 feet of the left abutment has a shallow, irregular topography which steepens rapidly above this elevation and has an average slope of about 20° to the crest of the proposed dam (elevation 1860). The sharp break in slope appears to be controlled by a zone of shearing and brecciation. Good, though isolated, outcrops of this fault zone are well exposed in road cuts. The remainder of this fault zone is covered by soil and colluvium and its dimensions and exact attitude could not be determined during the brief reconnaissance without subsurface exploration. The major fault zone which crosses the channel and the right abutment passes over the left abutment downstream from the axis. Four dozer trenches were excavated along the trace of this zone to ascertain the location of the fault zone and to gain some knowledge of the suitability of this material in the foundation. All four trenches encountered intensely brecciated, sheared, and partially serpentinized meta-volcanic rock which appears to be typical of this fault zone. Locations of the four trenches are shown on Plate 32.

The upper portion of the left abutment is underlain by moderately weathered and jointed dark green foliated to massive meta-volcanic rock. Outcrops are spotty but the cover of soil and colluvium does not appear to be deep -- the average is about 5 feet. The rock is both of intrusive and extrusive origin and is hard and resistant when fresh. No construction difficulties are anticipated in this material after removal of deeply weathered and jointed rock.

Based on surficial geologic reconnaissance and four dozer trenches the following foundation preparation will be required on the left abutment:

1. Remove all colluvium, talus, and loose weathered rock from the entire abutment. An additional 10 feet of weathered rock should be removed under the impervious section. The depth of colluvium is highly variable -- the lower abutment is covered by deep overburden to a depth of about 15 feet and the overburden on the upper abutment slope averages about 5 feet. Two deposits of deep slopewash located up- and downstream from the axis should be removed entirely to prelcude any possibility of sliding into the dam embankment.

2. The two fault zones will require extensive overexcavation to a depth of at least 50 feet and should be backfilled with concrete or other suitable material. Narrow fault zones paralleling the major zones of weakness should be expected under the colluvium. These minor faults should be overexcavated to a depth of at least 5 feet and backfilled with dental concrete. The cut slopes for the fault zone excavation will be in intensely fractured meta-volcanic rock adjacent to the faults, and side slopes should be as shallow as 1-1/2 to 2:1.

Spillway

The best suited spillway location for the proposed dam lies above the right abutment and would require an excavation 320 feet deep. The spillway will be of the chute type, terminating in a flip bucket which will discharge into Eltapom Creek (see Plate 32). A 100-foot-high narrow "nose" of rock will have to be removed at the mouth of Eltapom Creek and the channel will need improvement to provide an unrestricted get-away channel discharging downstream from the toe of the dam. The spillway will be entirely in hard, moderated blocky meta-volcanic rock with occasional thin interbeds of slate. No detailed study of the directions of joints, minor shears, and foliation was made during the reconnaissance stage; however, the prevalent direction of foliation and fracturing appears to be roughly north-south. A detailed study of the structure should be undertaken as it will have a profound effect on the stability of the cut slope, methods of excavation, and the quality of the rock produced. The cut slopes should stand on 1/2:1 in fresh rock with benches every 50 feet. The upper 50 feet of the excavation will be in intensely to moderately weathered and fractured rock and should stand on a 1:1 slope.

In the preliminary design stage both the approach channel and the chute were entirely concrete lined. Detailed study, including diamond drilling, is required to determine the extent of lining that will be needed.

Diversion Tunnel

Diversion during construction and later the operation of outlet works will be through a 40-foot tunnel under the right abutment. The alternative location under the left abutment appears to be geologically less favorable as it would encounter a greater percentage of crushed fault zone material.

The 40-foot-diameter, 4,700-foot long tunnel through the right abutment will have to be 100 percent lined and supported. The tunneling conditions anticipated are summarized below in tabular form.

Rock Description	Length of Heading in Feet	Tunneling Conditions	Load Factor
Moderately fractured fresh and hard meta-volcanic rock	4150	Moderately blocky and seamy	0.35 (B+Ht)
Intensely fractured meta-volcanic rock and slate interbeds	300	Very blocky and seamy	0.75 (B+Ht)
Fault zone material	250	Completely crushed may be moderately squeezing	1.1 (B+Ht)

Construction Materials

Based on a preliminary estimate the following embankment volumes of material will be required for a dam with a crest elevation of 1920.

Impervious - 26,000,000 yds^3

Pervious gravel - 19,000,000 yds^3

Rockfill - 41,000,000 yds^3

A limited borrow study for middle Eltapom damsite was conducted in 1957; however, further reconnaissance was required in 1963 to locate additional materials. No auger work was accomplished at either time. Location of the various types of materials and estimated quantities are shown on Plate 33, "Location of Construction Materials, Eltapom Damsite"

Impervious Material. Sources of impervious material as outlined on Plate 33 consist of poorly consolidated continental sediments of the Weaverville formation of Tertiary age. Rock types found within this formation are poorly to moderately compacted shale, moderately compacted fine silty sandstone, and conglomerate with silty to clayey matrix and occasional thin seams of coal. No exploration or sampling of these deposits has been accomplished at this date; however, based on surficial observation these sediments appear to be suitable for the impervious section of a thick core dam. Overall, the Weaverville sediments have an average composition corresponding to a silty sand and have a rather low plasticity. The upper weathered zone, which extends to a depth of about 15 feet, has a higher clay content and is more plastic. Near the southwestern boundary of Hyampom Valley the Weaverville beds have the composition of silty to clayey gravel and seem to be well suited for impervious fill. Detailed geologic mapping is needed to determine the extent and quality of this material.

All Tertiary sediments are moderately compacted and will require ripping below the weathered zone. The ripped material will consist of many subangular fragments up to 8 inches in diameter which will break up sufficiently after several passes of a tamping and grid roller to produce a satisfactory impervious section. To assure adequate breakdown this material should be placed in shallow lifts (6 to 8 inches).

Preliminary geologic mapping indicates that more than 50 million cubic yards of Weaverville sediments are available with a 4-mile radius from the site. The most extensive deposit is located along the southeastern boundary of Hyampom Valley about 3 air miles from Eltapom damsite.

Pervious Material. The Hyampom Valley is overlain by an extensive alluvial sand and gravel deposit which developed after the river was partially blocked by a large landslide downstream from the proposed dam. This deposit of previous material is shown as Areas P-1 and P-2 on Plate 33.

The total estimated volume of Areas P-1 and P-2 is 21 million cubic yards, assuming an average depth of usable material at 30 feet. The alluvium is also suitable, after proper processing for filters and concrete aggregate.

Area P-1 was explored with three trenches and two representative samples of this material were obtained.

Area P-2, which is similar to P-1 but contains somewhat finer grained material, was explored by one trench from which two samples were obtained. Both proposed borrow areas appear to be well suited for the gravel fill section of the proposed dam.

Rockfill. Two potential quarry areas outlined on Plates 33 and the salvage from the spillway excavation will provide an adequate volume of rockfill for the proposed dam. Either of the two quarry areas, Q-1 or Q-2, contains a sufficient volume of rock for construction of the Eltapom Dam; however, it appears that operation of both quarry areas up- and downstream from the site could be more economical. The potential quarry sites consist of hard, moderately jointed meta-volcanic rock with minor, thin interbeds of foliated greenstone, slate, limestone, and serpentine. Based on surficial observation the rock is of good quality for the proposed rockfill sections.

Conclusions

1. Based on present knowledge of the foundation conditions, the proposed Eltapom damsite cannot be recommended for a 720-foot-high fill structure. A detailed exploration and geologic mapping program is required to determine whether the site is suitable for a high fill dam or to determine the maximum structure which can be safely constructed at this location.

2. At least two major fault zones cross the dam foundation under the maximum fill section and constitute a major foundation defect. The fault zone material consists of intensely sheared and brecciated meta-volcanic rock with lenses or zones of clayey gouge and sheared serpentine, as determined by geologic mapping and four dozer trenches on the lower left abutment.

The general location and dimensions of the fault zones are shown on Plate 32, but the width, direction of dip, and characteristics of fault material can not be determined without an extensive subsurface exploration program. The fault zones are mantled by deep colluvium and outcrops are confined to isolated roadcuts and spotty, probably slumped gouge exposures near the stream channel. The proposed foundation treatment will consist of removal of all colluvium and the fault zone material will be overexcavated to an additional depth of at least 50 feet.

3. The channel section is covered by alluvium to a maximum depth of at least 70 feet. The alluvium should be removed from the entire dam section to facilitate inspection of the underlying bedrock.

4. The right abutment appears to be best suited for a spillway location. The higher elevation plans with crest elevation of 1820 and 1920 will utilize a chute spillway which would discharge into Eltapom Creek. Considerable channel excavation in Eltapom Creek will be required for unrestricted flow.

A side channel spillway across the right abutment may be more economical for lower elevation plans owing to increase in depth and width of the excavation. The spillway cuts will be almost entirely in hard, moderately jointed meta-volcanic rock and side slopes should be stable at 1/2:1 with benches every 50 feet.

5. The 40-foot-diameter outlet tunnel will cross a major fault zone and will have to be 100 percent supported and lined. At least 250 feet of the tunnel will be in complete crushed, moderately squeezing rock.

6. An adequate volume of construction materials has been outlined for the proposed dam during the preliminary geologic reconnaissance. An extensive geologic mapping, sampling, and testing program is required for a proper evaluation of the availability of embankment material.

7. A preliminary foundation study for a downstream axis should be initiated. The projected fault zone which is shown crossing the left abutment and the channel section of the downstream site may continue to the northwest away from the dam foundation into the upper portion of Big Slide. The present location of the fault is based on slumped outcrops and slide debris which may not be in place. The exploration of this site should be directed to ascertain the presence of a major fault within the dam foundation.

The construction of a dam at this lower site will require the removal of the entire Big Slide to prevent sliding into the embankment section.

Recommendations

1. The following foundation exploration is recommended to determine the suitability of the foundation for the proposed structure.

a. Additional trenches along the fault zones on both abutments. The trenching exploration should expose the entire width of both zones and determine the dip and the characteristics of the fault zone material.

b. The entire dam foundation should be mapped in detail on a topographic map with a scale of at least 1-inch = 100 feet. The geologic mapping should be concurrent with the trenching exploration. Additional trenches should be excavated as indicated by geologic mapping.

c. Large scale insitu testing of the exposed fault material is recommended for a quantitative determination of the shear strength, bearing capacity, and permeability of this rock.

d. At least two adits should be excavated on both abutments within the fault zones and large scale insitu tests should be performed.

e. The foundation should be explored by an extensive diamond drilling program. The drilling should follow the trenching and detailed geologic mapping. Additional diamond drilling will be required along the spillway excavation and the diversion tunnel alignment.

2. Sampling and testing of the potential source areas of construction materials is needed. This exploration program should include a test quarry at one of the proposed rockfill sources.

3. Geologic mapping, trenching, and diamond drilling of the lower site is required to determine if this alternate site is feasible.

Alternative Eltapom-Big Bar Tunnel

The alternative Eltapom-Big Bar Tunnel is part of the North Coastal development scheme of The California Water Plan. The tunnel is designed to divert the water of the South Fork Trinity River northward into the proposed Big Bar Reservoir on the main Trinity River.

The purpose of the geologic study was to make a preliminary evaluation of the tunneling conditions and to select the most economical tunnel alignment.

The geologic field reconnaissance was conducted in the fall of 1961 and consisted of surficial geologic mapping, projection of geologic conditions to proposed tunnel grade and the determination of tunneling characteristics of the various rock units. Based on this information, the most favorable tunnel alignment was selected.

Description of Project

The tunnel will convey water from the proposed Eltapom Reservoir on South Fork Trinity River into the Big Bar Reservoir on the main Trinity River. From Big Bar Reservoir the water will be transported via the Cottonwood Creek Tunnel and the West Side Conveyance System into the Glenn Reservoir Complex or via the Clear Creek No. 2 Tunnel into the Iron Canyon Reservoir on the Sacramento River (see Plate 1).

The optimum tunnel dimensions have not been determined at this time; however, the following tentative statistics were used for the preliminary cost analysis:

1. Tunnel length - 46,500 feet.
2. Type of tunnel - Lined and supported pressure tunnel.
3. Tunnel diameter - 16 feet.
4. Monthly discharge - 90,000 acre-feet.
5. Inlet elevation in Hayfork Creek (Eltapom Reservoir) - 1540 feet.
6. Outlet elevation Price Creek (Big Bar Reservoir) - 1500 feet.

Location and Access

The Eltapom-Big Bar Tunnel lies roughly 20 miles west of Weaverville and about 12 miles northwest of the town of Hayfork. The inlet portal on Hayfork Creek is located in Section 22, T3N, R7E, HB&M, and the outlet portal lies in Section 7, T33N, R12W, MDB&M.

The tunnel area is covered by the USGS Hyampom quadrangle with a scale of 1:62,500 and a contour interval of 50 feet. Virtually the entire area studied lies within the boundaries of the Trinity National Forest.

No principal or paved roads cross the tunnel alignment; however, access is provided by a well maintained Forest Service road and several logging and jeep trails. The inlet and outlet portal areas can be reached by the Hyampom-Hayfork road and State Highway 299, respectively.

All dirt roads and trails in the area may become inaccessible in the winter or after prolonged rainfall.

Description of Area

The Eltapom-Big Bar Tunnel region is characterized by steep rugged ridges and deep, narrow canyons typical of the Klamath Mountains geomorphic province. The highest point is Pattison Peak, 5,151 feet above sea level, while the portal areas lie at an elevation of about 1,500 feet.

Drainage is provided by Corral and Miners Creeks, tributaries to Hayfork Creek, and in the northern portion by Price Creek, a tributary of the Trinity River.

The entire region is blanketed by a dense fir and pine forest. Locally the slopes are covered by heavy brush and poison oak which constitute a deterrent to geologic field work.

Outcrops of bedrock are relatively scarce due to deep weathering and accumulation of soil and colluvium. The best rock exposures are generally confined to bottoms of canyons and to recent roadcuts.

Regional Geology

The regional geologic setting of the tunnel area is described in Bulletin No. 179 (1960), California Division of Mines, entitled "Geologic Reconnaissance of the Northern Coast Ranges and Klamath Mountains, California". Bulletin No. 179 covers in considerable detail the stratigraphic and structural relationships of the region and has become an important reference for engineering geologic investigations in the North Coastal Area. The bulletin contains a reconnaissance geologic map on a scale of 1:500,000 and an extensive list of geologic references.

This report places emphasis only on the tunneling conditions along the proposed alignment and contains only a sketchy description of the regional geologic picture. The interested reader should refer to Bulletion No. 179 for an authoritative up-to-date discussion of the regional geologic relationships.

Rock Units

The tunnel area is underlain by four principal rock units or geologic formations: Chanchelulla group, Ironside Mt. diorite, serpentine and ultrabasic intrusives, and Weaverville formation. Geology of the tunnel alignment is shown on Plate 34, "Geologic Map and Section, Eltapom-Big Bar Tunnel".

Chanchelulla Group. The rocks of the Chanchelulla group are chiefly meta-sediments, meta-volcanics, chert, and limestone. The age of the Chanchelulla group is poorly established and appears to vary from late Paleozoic to Triassic.

1. Meta-sediments. Fine-grained, slightly meta-morphosed marine sediments are the most abundant rock types found in the tunnel region. The rock is generally a fissile carbonaceous slate with a moderately well developed slaty cleavage. Overall the rock is moderately fractured and is quite hard and competent when fresh.

Locally, the slates have been considerably sheared and deformed, especially where slate is interbedded with harder rock such as chert and greenstone. In these areas of intense deformation, slates may grade into phyllite or into partially recrystallized quartz-mica schist.

Slates are usually thinly bedded and are interstratified with lenses of chert, greenstone, and limestone. In the tunnel area slates occur in discontinuous belts or lenses which rarely can be traced over a distance more than 1 mile.

2. Meta-volcanics. Altered volcanic rock -- generally referred to as greenstone -- is one of the most abundant rock types in the tunnel area. Greenstone appears to be predominantly of extrusive origin, although some bodies of meta-volcanic rock are intrusive. In fresh outcrop, the rock is a hard, massive, moderately jointed rock with

a characteristic green color and an aphanitic, glassy texture. Volcanic textures are preserved in some outcrops; however, subsequent silicification has usually obliterated the original texture. Greenstone is one of the most resistant rocks in the area and forms bluffs and gorges in creek channels.

3. Chert. Chert is generally found in small lenses throughout the tunnel area interbedded with greenstone and slate, and constitutes an important portion of the Chanchelulla group (about 20 percent in tunnel area).

The rock is very hard and brittle, thinly stratified to massive and is moderately jointed. Chert has a variety of colors varying from green to black to red brown.

A large body of thinly bedded chert crops out just downstream of inlet portal A along Hayfork Creek where it forms prominent cliffs.

4. Limestone. Limestone is the least common unit of the Chanchelulla group. It is found throughout the area in small lenses or pods and constitutes no more than 1 percent of the entire group.

Ironside Mountain Batholith. The Ironside Mountain batholith is an elongated body of intrusive igneous rock which covers an area of about 200 square miles, and is the largest batholith in the Klamath Mountains Province.

In the tunnel area the batholith is about 4 miles wide, trends N60-70W, and is nearly normal to the tunnel alignment (see Plate 34).

The intrusive rock consists predominantly of medium-grained hornblende diorite grading locally into quartz diorite. The batholith contains numerous basic segregations or inclusions and is crossed by innumerable quartz veins. Along the northern contact a zone of markedly more basic rock was mapped. This zone is about 1/2 mile wide and is typified by inclusions of almost pure hornblende, and by fine-grained igneous rock.

Outcrops of fresh diorite are confined to stream channels (Hayfork Creek) and to recent roadcuts. Higher on the ridges, outcrops are scattered and are surrounded by decomposed rock.

Serpentine and Ultrabasic Intrusives. Numerous small, irregularly shaped bodies of serpentine were mapped near the inlet portal.

The serpentine is associated with small stocks of relatively unaltered ultrabasic rock and appears to be confined to an area underlain predominantly by meta-volcanic rock (see Plate 34). The precise relationship between the greenstone and the serpentine was not established during the brief field study but it appears that serpentine was injected along shears and fracture zones and may be related to the volcanic rock.

The serpentine represents altered periodotite and traces of original coarse-grained texture are often discernible. Small "patches" of relatively unaltered ultabasic rock are found throughout the serpentine bodies. These have a composition ranging from gabbro to pyroxenite.

Weaverville Formation. Loosely consolidated sediments of the Weaverville formation were mapped in Corral Bottom and west of the tunnel outlet near the channel of Trinity River. The rocks consist of clayey gravel; soft, friable sandstone; and some shale.

Based on the results of the field reconnaissance, sediments of the Weaverville formation will not be encountered at tunnel grade.

Structural Relationships

Regional structural geology of the Klamath Mountain Province is described in considerable detail in California Division of Mines Bulletin No. 179. Structural relationships in the tunnel area are extremely complex owing to discontinuity of lithologic units and complex folding and faulting, and are further obscured by the scarcity of reliable rock exposures.

The geologic map of Bulletin No. 179 indicates that the tunnel line lies in an area of predominant NW trends. This structural grain trending roughly N60-70W is reflected in the topographic expression of the area controlled primarily by the Ironside Mountain batholith.

The attitudes of minor geologic features are much less consistent -- strikes and directions of cleavage or foliation varied throughout the tunnel area.

Folding. No major folds were traced in the course of the reconnaissance field mapping. The sedimentary and the interbedded volcanic units of the Chanchelulla group appear to be intricately folded and a detailed regional mapping program is necessary to delineate major fold trends.

Minor folding was observed in the Price Creek channel near the outlet portal in thinly bedded Chanchelulla slates.

Faulting. Several large faults and shear zones were defined during the brief geologic reconnaissance. In addition to these, a number of minor faults and shears were mapped.

The major zones of weakness crossing the tunnel alignment are described below:

1. A zone of sheared and fractured rock was mapped in the inlet area with serpentine and ultrabasic rock injected into the fracture zone. The serpentine appears to be confined to shears and areas of intense fracturing and occurs in small discontinuous, irregularly shaped bodies. Subsequent deformation caused extreme crushing and brecciation in the less competent serpentine and locally reduced the rock to a clayey gouge.

The extent of the fracture zone outside of the tunnel area was not traced; however, it appears to line up with serpentine on the north side of Hyampom Valley.

Hazardous tunneling conditions are anticipated in serpentine and in the crushed, brecciated material. The entire fracture zone was classified as tunneling conditions Zone IV.

2. A northwest-trending major fault marks the southern boundary of the Ironside Mountain batholith in the tunnel area. The fault zone is about 100 feet wide and is characterized by clayey gouge and sheared, brecciated serpentine. Based on the surficial trace of the granite contact, the fault appears to be essentially vertical.

Several small springs issue from sheared fault zone material near Gates Creek and may be an indication of hazardous water conditions at tunnel grade.

3. The southern contact of the granitic rock along Corral Creek appears to be a northwest-trending fault. Although no outcrops of fault zones were found, the abrupt termination of the batholith along an almost straight line strongly suggests a fault relationship. The projection of this inferred fault zone will intersect the tunnel line under Corral Creek (see Plate 34). Lack of outcrops precludes a detailed evaluation of the tunneling conditions; however sheared, gougy rock and high water flows are expected at depth.

4. A number of shear zones were mapped in the channel of Price Creek near the tunnel outlet portal. These zones of weakness are relatively narrow and should not present any significant tunneling difficulties. Water inflows should be moderate owing to low depth of cover.

Tunneling Conditions and Cost Factors

Four tunneling conditions zones were differentiated in the course of geologic mapping. These are summarized on Table 19 and shown on the geologic cross section, Plate 34. These zones are not necessarily delimited by lithologic or formational boundaries but are more closely related to the physical properties of the rock within a particular area crossed by the tunnel. Factors such as the degree of fracturing, chemical alteration, hardness, schistosity, and stratification were taken into consideration in outlining the tunneling zones.

The four zones on Plate 34 represent the inferred average tunneling conditions of the entire zone. Considerable variation in the competency of the rock can be expected at a particular point or interval within a tunneling zone.

Terzaghi rock load factors were assigned to the rocks of a tunneling zone. These factors are based on the physical properties and are to be used in determining the cost of tunneling.

The following seven rock conditions and corresponding Terzaghi load factors have been adopted for use in tunnel cost estimates of the North Coastal Area tunnels:

Rock Condition	Description	Terzaghi Load Factors
1	Hard intact rock. May be light spalling, no support required.	0
2	Massive, moderately jointed. Light support and/or rock bolts required (Load may change erratically).	0.25 B
3	Hard stratified or schistose. Light support and/or rock bolts required.	0.5 B
4	Moderately to very blocky and seamy. Support required. No side pressure.	0.35 $(B + H_t)$ or 0.7 B
5	Completely crushed but chemically intact. Some side pressure. Invert struts required.	1.10 $(B + H_t)$ or 2.20 B

Rock Conditions	Description	Terzaghi Load Factors
6	Squeezing rock. Heavy side pressure. Circular support required.	2.10 $(B + H_t)$ or 4.20 B
7	Squeezing, swelling rock. Great depth. Heavy circular support required.	4.50 $(B + H_t)$ or 9.00 B

Zone I. Tunneling conditions in Zone I include all the rock units of the Ironside Mountain batholith.

Lack of outcrops along the proposed tunnel alignment did not permit detailed mapping within the mass of diorite. Rock conditions observed a considerable distance from the tunnel line in Hayfork Creek and along the Hyampom-Burnt Ranch road were assumed to be typical of the entire batholith and were used in the determination of cost factors.

Near the surface the diorite has been decomposed by weathering to "dg". The depth of weathering should average about 100 feet and may reach an occasional depth of 150 feet in sheared or closely jointed zones. No weathered rock is expected to be encountered at tunnel grade.

Rock conditions for almost the entire Zone I at invert elevation are expected to range from hard intact to hard moderately jointed. Outcrops along the Hyampom-Burnt Ranch road indicate that the batholith contains a number of shear zones which are typified by closely spaced joints, hydro-thermal alteration, and occasional gouge seams. Shear zones in the immediate tunnel area are not exposed owing to deep weathering, but are anticipated at depth. Rock conditions in shear zones will vary from very blocky and seamy to completely crushed with clay gouge.

High water inflows are expected to occur in shears and closely jointed zones. Hydrostatic pressures may be very high in areas under great depth of cover.

Tunneling conditions in granitic rocks are extremely difficult to predict from surface exposures. Past experience indicates that hazardous conditions are confined to relatively narrow zones which contain crushed rock and may yield very high quantities of water -- at times causing the sheared rock to flow into the tunnel. A pilot hole ahead of the heading, while tunneling through granite, has generally proved to be a profitable precautionary measure.

Summary of Tunneling Zone I

	Rock Condition	Load Factor	Percent of Zone
1	Intact; no support.	0	25
2	Massive, moderately jointed; light support and/or rock bolts.	0.25 B	70
5	Completely crushed - chemically intact. Some side pressure.	1.10 $(B + H_t)$	5

Zone II. Zone II tunneling conditions include the meta-volcanic rock units of the Chanchelulla formation. The meta-volcanics are generally hard, fine-grained, and moderately jointed. Locally the rock shows rough foliation and may be interbedded with meta-sediments.

Zone II tunneling conditions should vary from massive, moderately jointed to moderately blocky and seamy. Horseshoe steel support will be required to support light to moderate rock loads. Overbreak is expected to be light -- average joint spacing is estimated at 2.0 feet. No lateral pressures are anticipated in meta-volcanic rock; however, spalling may occur in intact, brittle rock.

Hazardous water inflows should be confined to narrow zones of closely spaced interconnected joints or to shears containing premeable crushed material, under considerable depth of cover.

Summary of Tunneling Zone II

	Rock Condition	Load Factor	Percent of Zone
2	Massive, moderately jointed; light support and/or rock bolts.	0.25 B	60
4	Moderately blocky and seamy to very blocky and seamy. Support required.	0.35 $(B + H_t)$	40

Zone III. Zone III tunneling conditions include the meta-sedimentary rock types of the Chanchelulla group. Chanchelulla meta-sediments consist predominantly of slate with subordinate amounts of phyllite, schist, and lenses of chert, meta-volcanics, and limestone.

The rocks are generally stratified to schistose and are moderately jointed. The intensity of fracturing and shearing is extremely erratic and is difficult to predict at depth. Outcrops along the channel of Trinity River and Price Creek indicate that slates interbedded with more resistant lenses of chert and meta-volcanic rock are often sheared and altered along contacts. Shearing and brecciation is generally confined to lenses of less competent material while the surrounding harder rock units are generally undeformed.

Tunneling conditions in meta-sediments are expected to vary from hard and stratified or schistose to moderately blocky and seamy with relatively narrow zones of crushed gougy material. Considerable overbreak should occur along the intersection of closely spaced foliation and joint planes.

Rock load, support requirements, and overbreak are expected to vary erratically throughout the entire zone.

Summary of Tunneling Zone III

	Rock Condition	Load Factor	Percent of Zone
3	Stratified or schistose, light support.	0.5 B	25
4	Moderately to very blocky and seamy. Support required.	0.35 $(B + H_t)$	65
5	Completely crushed - invert support required.	1.10 $(B + H_t)$	10

Zone IV. Tunneling Zone IV includes the rocks associated with serpentine and ultrabasic intrusives near the inlet portal and along major faults (see Plate 34). The serpentine appears to have been intruded into an area of strong deformation and intense shearing. The deformation may also be in part related to the expansion of ultrabasic rock during the serpentinization process.

Fault zones are characterized by sheared, brecciated rock with clayey gouge. Two major faults were mapped crossing the tunnel alignment.

Portions of Zone IV consist of relatively undeformed and intact meta-volcanic or meta-sedimentary rock; however, the undeformed material is surrounded, and may be underlain by serpentine and sheared rock.

Tunneling conditions should range from very blocky and seamy to completely crushed. Light lateral pressures are anticipated in Zone IV owing primarily to low depth of cover. Water inflows may be considerable, except along faults, but no high hydrostatic pressures should be encountered. Highest flows may occur below the channel of Corral Creek with water flowing into the tunnel bore through interconnected fractures. Grouting ahead of the heading may be required.

Tunnel excavation in Zone IV will be by the multiple drift method. Invert struts and close blocking will be required to counteract lateral pressure in intensely sheared gougy material.

Summary of Tunneling Zone IV

Rock Condition	Load Factor	Percent of Zone
4 Very blocky and seamy. Support required.	$0.35\ (B + H_t)$	50
5 Completely crushed rock at low depth of cover. Some side pressure - invert struts required.	$1.10\ (B + H_t)$	50

Portal Locations

Two alternative inlet portals (A and B) are indicated on Plate 34. Portal A is in sheared and altered meta-volcanic rock, intruded by serpentine. Owing to intense deformation the rock in the portal area A is deeply weathered and will require considerable preparatory excavation to establish a safe face for a tunnel portal.

Portal B will lengthen the overall tunnel length by about 1,500 feet, but is located in hard, thinly bedded chert and meta-volcanic rock. No extensive excavation or scaling appears to be necessary for a satisfactory tunnel portal. Based on preliminary surficial geologic observations the location of the tunnel portal at B is more advantageous and warrants the slight increase in overall tunnel length.

The outlet portal is located in thinly bedded, moderately weathered meta-sedimentary rock. The rock appears to be relatively unfractured and should not present any unusual construction difficulties.

Water

The average annual precipitation in the Eltapom-Big Bar Tunnel area is 45 to 50 inches, and provides the principal means for ground water recharge. Numerous small springs were noted above invert grade and virtually all streams with more than about 1.5 square miles of drainage area are perennial.

The quantity of water stored above the tunnel grade (1,500 elevation) is not known. Dense vegetation blankets the region and may retard runoff sufficiently to permit considerable quantities of water to seep into the fractures and joints. All rock types in the tunnel region -- with exception of the Weaverville formation which is not present at grade -- are non-porous and ground water movement should be confined to bedding planes and fractures.

Water flows in the tunnel are anticipated to be highly erratic and unpredictable. The highest flows will be encountered in water-bearing fault and shear zones and along interconnected fractures, under high depth of cover. About 3 percent of the entire tunnel will be wet heading excavation in relatively competent rock.

No hot or deleteriously mineralized springs were noted. Several springs near the inlet portal flowing from meta-volcanic rock appeared to be mildly sulfurous. Analysis of one of these spring waters indicates that they are calcium bicarbonate in character with a low concentration of dissolved solids. Near the outlet several springs were located which have left deposits of tufa ($CaCO_3$). The source of these springs appears to be related to an east-west trending fault. Analysis of one of these springs also indicates a calcium bicarbonate character with low total dissolved solids.

Concrete Aggregate

Sources of alluvial gravel suitable as concrete aggregate for tunnel lining have been located a reasonable distance from both the inlet and outlet portals.

Aggregate near the inlet is in Hyampom Valley. Extensive gravel deposits are available from the Eltapom Reservoir area about 5 miles from the inlet portal. This material will also be used in the pervious section of the Eltapom dam. No estimate of usable volume of gravel was made.

Aggregate near the outlet is available as follows: (1) limited volumes of gravel are found along the channel of Trinity River both up- and downstream of Big Bar, and (2) extensive deposits are located at Junction City about 10 miles from the outlet portal.

Conclusions

Based on reconnaissance geologic mapping without benefit of subsurface exploration, the following conclusions were reached:

1. The proposed Eltapom-Big Bar Tunnel line appears to be geologically feasible.

2. Tunneling conditions are anticipated to be generally quite good and no unusual tunneling hazards should occur.

3. Four distinct tunneling condition zones were differentiated in the course of reconnaissance geologic mapping -- Zone I through IV. These zones are based on physical properties of the rock units and are not necessarily delimited by geologic boundaries (see Table 19 and Plate 34). The best tunneling conditions will be encountered in Zone I and worsen progressively through Zones II, III, and IV.

4. Steel support will be required in all but 25 percent of Zone I. Moderate lateral pressures are anticipated in sheared gougy rock near the inlet portal and in narrow isolated fault and shear zones throughout the tunnel line. Squeezing rock, requiring invert struts, should constitute about 5 percent of the entire tunnel line.

5. Lining will be required throughout the entire tunnel with the exception of 25 percent of Zone I.

6. About 3 percent of the tunnel line is considered to be wet heading tunneling in competent rock. All rock units at tunnel grade are non-porous and ground water should be confined to permeable faulted and sheared rocks and to interconnected joints and foliation planes. It is anticipated that water inflows in the tunnel will be encountered in relatively narrow zones and should be erratic and unpredictable.

No hot or deleteriously mineralized ground water was found in the tunnel area and should not occur at tunnel grade.

7. The inlet portal area is underlain by sheared, brecciated meta-volcanic rock and serpentine. Considerable construction difficulties are anticipated at portal location A, which lies in highly deformed rock.

Portal location B lies in hard, competent chert and appears to be more suitable. The outlet portal in Price Creek is located in competent rock and should not require extensive excavation or scaling.

8. The tunnel should be constructed to withstand moderate earthquake shocks. The tunnel area is located in an area of low seismic activity (see Plate 2).

9. Adequate quantities of suitable concrete aggregate are located within 10 miles of the tunnel portals.

Recommendations

1. Future engineering geologic studies of the Alternative Eltapom-Big Bar Tunnel will require a detailed topographic map of the tunnel alignment with a scale of about 1-inch = 1,000 feet.

A large scale map will permit detailed evaluation of geologic relationships and will enable the geologist to project the tunneling conditions to invert grade with a certain degree of accuracy.

2. Geophysical surveys should be made along the proposed alignment to locate more precisely fault zones and geologic boundaries and to detect the presence of serpentine below the surface. A magnetometer survey along the inferred fault in Corral Creek should be undertaken.

3. Exploratory drilling should be performed along the alignment to determine the extent of weathering, jointing, and fracturing to correlate surficial geologic observations with tunneling conditions at depth.

4. Exploratory adits or drifts -- especially in Zone IV rock near the inlet portal -- to test the actual tunneling characteristics under considerable depth of cover.

TABLE 19

SUMMARY OF TUNNELING CONDITIONS
ALTERNATIVE ELTAPOM-BIG BAR TUNNEL

Tunneling zone	Rock units	Rock conditions	Rock load factors (ft.)	Percent of zone	Excavation	Overbreak	Support
Zone I	Intact to slightly jointed diorite.	1. Hard, intact rock.	0	25	100% hardrock. Full face excavation.	Minimum overbreak. Light spalling may occur.	Occasional rock belts where needed.
	Hard, moderately jointed diorite.	2. Massive, moderately jointed.	0.25 B	70	100% hardrock. Full face excavation.	Low overbreak, along intersections of joint planes	Steel ribs on 6' centers. Rock belts where necessary.
	Sheared, gougy diorite.	5. Completely crushed. Some lateral pressures.	1.10 (B+Ht)	5	50% hardrock. Multiple drift excavation.	High overbreak.	Steel ribs on 2' centers, with invert struts if necessary.
Zone II	Hard, intact meta-volcanic rock. Slightly fractured.	2. Massive, moderately jointed.	0.25 B	60	100% hardrock. Full face excavation.	Low overbreak, along intersections of joint planes.	Steel ribs on 6' centers, rock bolts where necessary.
	Foliated and moderately jointed meta-volcanics.	4. Moderately blocky and seamy to very blocky and seamy.	0.35 (B+Ht)	40	100% hardrock. Full face excavation.	Moderate to high overbreak.	Steel ribs on 4' centers.
Zone III	Foliated, relatively unfractured meta-sediments.	3. Stratified to schistose.	0.5 B	25	100% hardrock. Full face excavation.	Moderate overbreak along foliation planes.	Steel ribs on 6' centers.
	Moderately to severely jointed foliated meta-sediments.	4. Moderately to very blocky and seamy.	0.35 (B+Ht)	65	100% hardrock. Full face excavation.	High to moderate overbreak.	Steel ribs on 4' centors.
	Sheared, gougy meta-sediments.	5. Completely crushed. Some side pressures.	1.1 (B+Ht)	10	Multiple drift excavation by common methods.	High overbreak. Moderate lateral pressures anticipated.	Steel ribs with invert struts on 2' centers.
Zone IV	Intensely fractured meta-volcanics.	4. Very blocky and seamy.	0.35 (B+Ht)	50	100% hardrock. Full face excavation.	High to moderate overbreak.	Steel ribs on 4' centers.
	Crushed, gougy serpentine and meta-volcanics.	5. Completely crushed, light lateral pressures.	1.1 (B+Ht)	50	Multiple drift excavation.	High overbreak.	Steel ribs with invert struts on 2' centers.

Eltapom-Helena Tunnel

The tunneling conditions of the proposed Eltapom-Helena Tunnel were investigated during a brief geologic reconnaissance. The geology of the tunnel line from the south portal to Haypress Meadow (T4N, R8E, Section 28) is discussed under the Alternative Eltapom (Eltapom-Big Bar) tunnel report. The remainder of the alignment (approximately 7 miles) to Helena Reservoir is underlain by rock types of the Chancellula formation which will present tunneling conditions identical to those described in the Alternative Eltapom tunnel report. The outlet portal would be located in Eagle Creek, located just upstream from the axis of Helena damsite.

The following tunneling conditions and load factors should be used for preliminary cost estimates on the section of tunnel not covered by the above-mentioned report.

Zone II*

Rock Condition	Load Factor Hp (in feet)	Percent of Zone
2 Massive, moderately jointed.	0.25 B	60
4 Moderately blocky and seamy.	$0.35\ (B + H_t)$	40

About 3.5 miles of the tunnel will be underlain by Zone II meta-volcanic rock.

Zone III*

Rock Condition	Load Factor Hp (in feet)	Percent of Zone
3 Stratified to foliated.	0.5 B	25
4 Moderately to very blocky and seamy.	$0.35\ (B + H_t)$	65
5 Completely crushed.	$1.10\ (B + H_t)$	10

* A detailed description of tunneling conditions in Zones II and III appears in the Alternative Eltapom-Big Bar Tunnel report.

Zone III is underlain by foliated meta-sedimentary rock of the Chancellula formation and about 3.5 miles of the tunnel will be in this zone.

Further detailed geologic mapping of the tunnel line is recommended to determine the tunneling characteristics with a greater degree of accuracy and to delineate any potentially hazardous zones.

War Cry Tunnel

The proposed War Cry Tunnel alignment would convey water from the proposed Eltapom Dam (lower axis) on the South Fork Trinity River to Burnt Ranch Reservoir on the main Trinity River. A change of alignment from the one presented in this report would be required to divert water from either of the upstream locations (upper or middle axis). Such a change of alignment would lengthen the tunnel by 1 to 1.5 miles from the present 10-mile length. The purpose of this investigation was to determine the geologic conditions along the proposed tunnel line from South Fork Trinity River to Trinity River.

This geologic exploration was done during the week of June 29 to July 4, 1958. Due to the short duration of field study, the conclusions presented herein are tentative and subject to revision following a more complete examination of the area.

The War Cry Tunnel area is in the Klamath Mountain province and lies within Trinity National Forest. It is located on portions of two USGS 15-minute topographic quadrangles; Ironside Mountain and Hyampom.

Location

The War Cry Tunnel extends southwestward from Don Juan Point about 4 miles east of Burnt Ranch on the Trinity River to the South Fork Trinity River in the vicinity of the U. S. Forest Service Big Slide Campground. The alignment as decided upon during the geologic investigation is as follows: South from Don Juan Point on the Trinity River to Chaparral Mountain in Section 6, T4N, R7E, HB&M, then approximately southwest to Underwood Mountain and then south-southwest to Big Slide Campground on the South Fork Trinity River.

Only the portal areas are readily accessible by road, although logging operations are rapidly opening new roads into the interior. The north portal is located across the Trinity River from State Highway 299, approximately 4 miles east of Burnt Ranch. The central portion of the tunnel can be approached (but not reached) via a logging road which leaves State Highway 299 at the Moss Lumber Company near Burnt Ranch. The south portal is located immediately across the South Fork Trinity River from Big Slide Campground approximately 6 miles by county road northwest of Hyampom.

General Geology

Due to the limited field work on the tunnel route few structural features have been mapped at the present time. Undoubtedly major fault zones are present throughout the area which will be revealed by detailed geologic mapping. The contacts between the intrusive igneous rocks and metamorphics are undoubtedly faulted in some places. However, the mapping done to date has not revealed their presence.

Folding in the metamorphic unit is not readily evident. A certain amount of shearing between certain rock types in this unit is evident, however. The main feature of this unit apparent along the river channels is the homoclinal structure with strike of N5° to 35°W and a dip of 55° to 65° northeast.

Table 20 summarizes the expected relative tunneling conditions in the mapped area. These vary from very poor to very good depending entirely upon the rock unit. The metamorphics to the west and the diorite to the east should present no formidable tunneling problems. However, the roof pendant of meta-morphics and the serpentine near the middle portion of the tunnel are both very questionable and will probably present considerable tunneling difficulty. Of the two latter rock types, the serpentine will present the greatest problem. Consequently, the tunnel route was aligned so that as little of the serpentine unit as possible would be intersected.

Rock Conditions

Rock conditions in each of four tunneling zones are described on Table 20. The tunnel would cross three generalized rock units: (1) meta-diorite, (2) serpentine and related rocks, and (3) meta-volcanics and meta-sediments.

Meta-Diorite. The tunneling characteristics of the meta-diorite unit should be good; the rock probably varying from intact to slightly jointed. The majority of this unit is thought to be of the former type. Although not yet mapped in detail the contacts with both the serpentine unit and metamorphic unit are thought to be fault controlled. Consequently, gouge zones and associated brecciation of the surrounding rocks should be expected. Overbreak should be no problem; however, small percentages of the tunnel through the meta-diorite should have slight to very moderate overbreak due to fracturing along any faults that may be present. If water in quantity is present in the fractured zones the high pressure possible will create a considerable problem. More field work must be done on the ground water problem.

Due to the intact to slightly jointed nature of the meta-diorite, rock load (Hp), support, and lagging factors of zero have been used. The excavation factor is slightly less than the maximum of 1.4 because of the moderately hard to slightly jointed nature of the meta-diorite. The minimum lining factor was used because of expected excellent condition of the major portion of this rock (see Table 20).

Serpentine and Related Rocks. The tunneling characteristics of the entire serpentine unit must be assumed to be very poor. Very blocky and seamy conditions plus the probability of squeezing ground will create vary difficult tunneling conditions. The great depth of overburden (almost 3,000 feet) will probably necessitate invert struts or circular ribs. Considerable quantities of water under high pressures will undoubtedly be contacted where the tunnel penetrates the extremely fractured zones in this unit. Overbreak must be assumed to be moderate to heavy because of the unpredictability of the serpentine unit.

Although the serpentinized ultramafic zones present in this unit have greater strength than the serpentine, the question of their dimensions and distribution relegates them to a position of minor importance. Further mapping may reveal distinct zones or bodies of considerable size which can be evaluated separately.

From the tunneling characteristics of the serpentine unit it is apparent that the alignment as considered in this report is highly desirable. Such an alignment will decrease the serpentine unit to be tunneled from 1,800 feet to 700 feet.

Due to the nature of the serpentine unit, the serpentine and serpentinized ultramafics have been grouped together in Table 20. A rock load (Hp) of 3.0 (B+Ht) is necessary because of probability of squeezing ground at moderate to great depths. Accordingly, the excavation, support, and lagging factors are determined by this same condition. An overall condition of heavy overbreak (lining factor = 1.5) must be assumed at this time.

Metamorphics - Meta-volcanics and Meta-Sediments. Approximately one-half of present tunnel alignment is located in the Chanchelulla meta-volcanics and meta-sediments. This unit is divided into two zones which should have different tunneling characteristics.

The first zone is comprised of 4,000 feet of highly altered and contorted meta-volcanics and meta-sediments in a roof pendant which are at least moderately blocky and seamy. The original stratification of the rocks in this isolated zone may take dominance over the massive character observed in the metamorphics to the north and south. Consequently, considerable moderate and heavy overbreak must be expected. If the tunnel alignment parallels the strike of the beds, special support problems should be expected. Further mapping will ascertain whether or not this condition exists. Ground water may be a problem if the brecciated zones are sufficiently open to allow passage of considerable volumes of water.

The moderately blocky and seamy to very blocky and seamy nature of this zone necessitated a rock load (Hp) of 0.7 (B+Ht). An excavation factor of 0.9 was used for this moderately hard and strongly jointed rock. Support and lagging factors were compromised at 0.8 and 1.0, respectively, because of the borderline nature of this unit. The lining factor of 1.0 was indicated because of the expected slightly greater than moderate overbreak.

The second zone of metamorphics comprises some 5 miles of tunnel line; however, these are probably massive to moderately jointed except along the contact with serpentine and along isolated shear or fault zones. Brecciation and gouge should be expected along these latter features. Although portions of this formation were originally stratified, limited observation revealed the unit to be considerably bonded together by a regional type of metamorphism. Consequently overbreak will be minor with a small amount of heavy overbreak expected in the fault or fractured zones. Ground water may be a problem if the brecciated zones are sufficiently open to allow passage of considerable volumes of water. At places where the tunnel passes beneath flowing streams, greater quantities of water should be expected.

In this zone a rock load of 0.3 (B+Ht) seems to be appropriate. The massive to moderately jointed nature of these metamorphics made possible support and lagging factors of 0.2 and 0.3, respectively. The excavation factor of 1.0 was obtained from the moderately hard overall character of the rocks of this unit. Slight overbreak is expected and therefore a factor of 0.7 is used.

Ground Water

Although no samples of ground water have been taken at this time, no temperature or quality problems are believed to exist. However, due to the very high depth of cover, extreme water pressures are possible at tunnel grade. The extreme depth of cover may help this problem by keeping the fractured zones in a state of compression thus decreasing if not eliminating water passage. Tensional forces, if present, however, would have adverse effects, i.e., open all fractures and joints.

Portals

The portal areas are thought to entail no problem whatsoever. The north portal is in the intact to slightly jointed meta-diorite unit and the south portal is in the better section of the massive to moderately jointed meta-volcanics - meta-sedimentary unit. Steepness of slope at both portals may necessitate benching out of the area to accommodate the necessary supplies and equipment.

Depth of Cover

The maximum depth of cover for the tunnel line will be about 3,600 feet and the depth for the major portion of the tunnel will be about 2,000 feet. Consequently, it is apparent that any tendency for squeezing rock in the serpentine unit will be accentuated by the large load.

Conclusions and Recommendations

1. The dioritic and main body of metamorphic rocks along the tunnel line should present no formidable tunneling problems. The extreme depth of cover for both rock units may cause some spalling rock in the dioritic unit; however, it is not thought likely in the metamorphic unit. The pendant of metamorphic rocks will present considerably more problems due to its blocky and seamy nature. The final unit is the serpentine in which very extreme tunneling conditions are expected. This is due to the depth of cover, squeezing ground, and isolated blocks of serpentinized ultramafics randomly distributed throughout the serpentine unit.

2. Faults and fault zones although not yet mapped are thought to be present along many of the igneous-metamorphic contacts. Other faults and shears may be present in the roof pendant of metamorphics due to its proximity to the highly sheared serpentine unit.

3. Because of the extreme depth of cover (average 3,000 feet) over the majority of the tunnel line, considerable water under very high pressure must be expected in the serpentine unit and possibly in the roof pendant of metamorphics. Water problems in the main metamorphic unit and the meta-diorite unit are not expected.

TABLE 20

WAR CRY TUNNEL
SUMMARY OF TUNNELING CONDITIONS

Station	Geology	Terzaghi Factors			Bulletin No. 3 Construction Factors			
Trinity River Portal		Rock Conditions	Rock Load Hp in feet	Remarks	Excavation	Support	Lagging	Lining
0 + 00 to 200 + 00	Meta-diorite	Intact to slightly jointed	0	Good tunneling except along contacts and shear zones. Some spalling rock expected.	1.3	0	0	0.7
200 + 00 to 240 + 80	Meta-volcanics and meta-sediments (Chanchelulla formation)	Moderately blocky and seamy	0.7(B+Ht)	Roof pendant - more metamorphosed than Chanchelulla below, possibly very blocky and seamy in places. Some heavy overbreak.	0.9	0.8	1.0	1.0
240 + 80 to 258 + 80	Serpentine and serpentinized ultramafics	Very blocky and seamy - also some squeezing ground	3.0(B+Ht)	Squeezing ground expected in serpentine. Serpentinized ultramafics probably moderate to very blocky and seamy. Considerably heavy overbreak and ground water under high pressures. Heavy side pressure.	2.0	3.2	2.0	1.5
258 + 80 to 530 + 80	Meta-volcanics and meta-sediments (Chanchelulla)	Massive to moderately jointed	0.3(B+Ht)	Partially stratified (cherts, slates, volcanic flows). Slight to moderate overbreak.	1.0	0.2	0.3	0.7
South Fork Trinity River Portal								

TABLE 21

GEOLOGIC CHARACTERISTICS OF DAMSITES

South Fork Trinity River

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
T4N,R6E,HB&M	Grouse Creek	South Fork Trinity River	The site is underlain by hard, medium to coarse grained diorite and fine grained metadiorite and metavolcanic rocks. Jointing is minor. Slides occur in the upstream and downstream toe areas.	Estimated for an earthfill dam 700' high. <u>Right Abutment</u> -- <u>Impervious section</u>: 40' - 50' slopewash and weathered rock. Pervious section: 20' - 25' slopewash and weathered rock. Remove all slide material. <u>Channel Section</u> -- <u>Fill stripping</u>: 15' sand, gravel, boulders. Bedrock stripping: Impervious section: 5' average for shaping. Pervious section: 1' - 2' for shaping. <u>Left Abutment</u> -- <u>Impervious section</u>: 50' slopewash and weathered rock. Pervious section: 20' - 25' of slopewash and weathered rock. Remove all slide material.	A spillway may be located around the end of the right abutment. Light to moderate lining may be required in diorite. Spillway cut slope may stand at 1:1 or steeper.		I-Slide debris is available near the site and upstream. Weaverville formation clayey gravels at Hyampom Valley 8 - 11 mi. upstream are suitable. P-Stream channel deposits near the site and alluvial sands and gravels in Hyampom Valley appear suitable. RF & RR-May be quarried at site.	Low	Low earthfill dam.	The presence of slides within the upstream and downstream embankment areas limits the suitability of this site.
NE 1/4 Sec.1, T2R,R6E,HB&M	Orel	South Fork Trinity River	The site is underlain by grey, massive limestone with interbedded, incompetent slaty shales. The attitude of bedding is, in general, nearly horizontal. The limestone is well jointed. Several shear zones underlie the site.	<u>Right Abutment</u> -- <u>Average 8' of soil</u> and bedrock. <u>Channel Section</u> -- <u>Little or no bed</u>-rock stripping necessary. Talus and boulders at base of left abutment need removal. <u>Left Abutment</u> -- <u>About 12' of</u> bedrock, loose rock and soil.	Excavation for a side-channel spillway across either abutment will probably be in hard rock. Slopes of the cuts should stand at 3/4:1.	A diversion tunnel would be bored in both limestone and shale. The most favorable location should be determined on the basis of a more detailed study of the geology of the damsite.	I-Terrace materials throughout reservoir area. Valley fill in Hyampom Valley. P-Stream channel deposits in reservoir area.	Moderate	Earthfill or low concrete gravity.	

CHAPTER VII. MAD RIVER - VAN DUZEN RIVER PROJECTS

Features being considered for the Mad-Van Duzen Project, a third stage of the Trinity River Development, are shown on Plate 1. The geology of these featured projects, discussed in detail in this Chapter, include Larabee Valley Dam, Larabee Valley Tunnel (alternative to the Van Duzen Pipeline), Eaton Dam, Mad River Tunnel, Anderson Ford Dam, and South Fork Tunnel. Geologic maps, cross sections, and maps showing location of construction materials for all these projects appear in this volume as Plates 35 to 42.

Geologic data on other damsites on the Mad and Van Duzen Rivers which have been studied briefly are presented on Table 23. These damsites include Ranger Station, County Line, Eight Mile, Butler Valley, Lower Butler Valley, Blue Lake, an enlarged Ruth on the Mad River, and Dinsmore, Camp, and Forks on the Van Duzen River.

Larabee Valley Damsite

Larabee Valley damsite is located on the South Fork of the Van Duzen River in Section 18, T1N, R5E, HB&M. The proposed axis is situated about 2,500 feet upstream from the mouth of Burr Creek. General access to the area is by means of State Highway 36 which traverses the upper right abutment.

A map of the damsite was enlarged to a scale of 1 inch = 1,000 feet from the USGS 15-minute Blocksburg quadrangle.

Description of Project

The Mad-Van Duzen Project would divert a firm annual yield of about 600,000 acre-feet into Eltapom Reservoir on the South Fork Trinity River. In addition to Larabee Valley Dam, other units of the Mad-Van Duzen Project include: Eaton Dam, Anderson Ford Dam, an enlarged Ruth Dam, Butler Valley Dam, Mad Tunnel, and South Fork Tunnel.

The preliminary design indicates a homogeneous fill-type section with downstream chimney and horizontal drains and a riprap blanket on the upstream face. A 56,000-cfs spillway is located on the left abutment and consists of an uncontrolled ogee weir and a concrete-lined chute terminating in a stilling basin. A 6-foot finished diameter diversion tunnel-outlet works is located through the right abutment.

Cost curve estimates were made for three different dam heights with normal water surfaces of 2,440, 2,540, and 2,640. A dam for any of these water surfaces would inundate Larabee Valley.

Geology of the Site

The entire damsite and reservoir area is underlain by the central belt of sedimentary and volcanic rocks of the Franciscan group. These rock types include sandstone, shale, greenstone, chert, and minor amounts of conglomerate. In addition, serpentine and glaucophane schist are associated with fault zones. Outcrops in this area are scarce, due to extensive landslides, slopewash, residual soil, and a moderate cover of vegetation. Plate 35, "Geologic Map and Sections, Larabee Valley Damsite", shows the geology of the damsite and surrounding area.

The topography at the damsite is moderately steep and irregular with a narrow, inner stream channel. On the right bank downstream from the site, extensive landslides were noted along Burr Creek. Upstream from the site the channel widens and alluvial terraces have been formed. Both abutments have been logged and soil creep is extensive.

Foundation Conditions

Right Abutment. The most striking topographic feature of the right abutment is a 500-foot-wide bench that occurs at elevation 2,500 feet. This bench narrows both upstream and downstream and is covered by high grass and a light growth of trees. The bench soils consist of an unknown thickness of gray, sandy, clayey silt (ML) with angular rock fragments. Since terrace-like gravels occur at the surface, the soil may be residual or represent an accumulation of slopewash. Only two outcrops were noted on the bench -- a small sandstone body and a sheared serpentine outcrop. However, excellent exposures of sandstone occur below the western edge of the bench. The following data is strong evidence for a fault zone beneath the bench soils: (1) highly sheared and partially serpentinized rock downstream from the site, at the right bank; (2) sheared serpentine and glaucophane schist float in the prominent draw upstream from the site; and (3) topographic and lithologic evidence on the bench itself (see Plate 35).

The right abutment is predominantly underlain by sandstone with lesser amounts of interbedded shale and greenstone. Typically, the sandstone is a rather massive graywacke with thin shale interbeds. Calcite and quartz veins are abundant locally. The sandstone is usually fresh and hard with weathering along open joints. Jointing is extensive and well developed. Attitudes are scarce and highly variable, and range from N30E to N10W in strike and 40°SE to 45°W in dip.

Areas composed of thinly bedded shale are typically slumped and highly weathered. An earthflow in sheared shale occurs on the upper right abutment near the proposed axis.

Channel. The channel section averages about 50 feet in width and the river gradient is moderately steep. The channel is choked with blocks and boulders up to 40 feet in diameter. Alluvial sands and gravels appear to average less than 5 feet in depth.

Greenstone plugs - composed of a complex assemblage of ultra-basics, meta-volcanics, and glaucophane schists - have been intruded into sandstone and shale in the channel and lower abutment areas. The sedimentary rocks surrounding the plugs have been altered, sheared, and serpentinized. Slopewash and talus have accumulated over bedrock along the base of the abutments. The character of the bedrock is therefore unknown because of these deposits.

A hard, massive greenstone monolith rises about 125 feet above the stream channel in the lower left abutment area downstream from the proposed axis. The river has eroded the base of this massive block and produced a slight overhang.

Special foundation treatment in the channel area will consist of: (1) blasting greenstone plugs and large talus blocks to shape channel, and (2) dental work along shears surrounding the greenstone plugs. No extraordinary grouting or drainage provisions are anticipated.

Left Abutment. The upper left abutment slopes are covered by either landslides, residual soil, or slopewash which support a moderate growth of vegetation. This area is probably underlain by sandstone and shale. The lower portions of the abutment are composed of deformed slaty shale with lesser amounts of meta-sandstone. The prevailing strike of the beds is N15E with 35°NW dips. Seeps were noted in shear zones and along the borders of the greenstone plugs.

Spillway. Limited time prevented a thorough spillway reconnaissance. As shown on Plate 35, a chute-type spillway is to be located on the upper left abutment. Depending on the size of the dam selected, the cut along the spillway crest will vary from 60 to 260 feet. It is estimated that the upper 15 feet of material -- consisting of residual soil or slopewash -- can be removed by common excavation. All remaining material, probably consisting of sandstone-shale (ratio unknown), will require hardrock excavation. Overall, spillway salvage of pervious to semi-pervious rock is assumed to be 50 percent. The entire chute channel should be concrete-lined. In addition, a stilling basin with a keywall is necessary to prevent erosion of soft, sheared fault material located at the re-entrance point.

Diversion Tunnel - Outlet Works. The diversion tunnel should be placed through the middle portion of the right abutment so as to avoid both the fault zone and the sheared rock surrounding the greenstone plugs. The 6-foot finished diameter tunnel will encounter sandstone and shale and will probably be 100 percent supported and lined. The rock is expected to vary from moderately blocky and seamy to very blocky and seamy.

Stripping Estimates

The following stripping estimates are for an earthfill dam 410 feet in height (NWS 2,640).

	Cutoff Section	Earthfill Section
Right Abutment		
(a) Upper Portion	10 ft. average - 5 ft. of slopewash and 5 ft. of weathered rock.	5 ft. of slopewash
(b) Bench	25 ft. average - 15 ft. of soil and 10 ft. of sheared rock.	15 ft. of soil and remove fault gouge.
(c) Lower Portion	15 ft. average - 10 ft. of slopewash and 5 ft. of broken rock.	10 ft. of slopewash.
Channel	10 ft. average - 0 to 5 ft. of sand and gravel and 5 ft. of jointed rock.	0 to 5 ft. sand and gravel and remove talus blocks to shape.
Left Abutment		
(a) Upper Portion	15 ft. average - 10 ft. of slopewash and 5 ft. of weathered rock.	10 ft. of slopewash

		Cutoff Section	Earthfill Section
(b)	Lower Portion	20 ft. average - 10 ft. of slopewash and 10 ft. of sheared and broken rock.	10 ft. of slopewash and remove sheared rock.

Removal of weak material in fault and shear zones may amount to greater than 20 feet of over-excavation in the foundation area. Close field control during construction will be necessary to determine a suitable cutoff point.

A grout curtain along the cutoff trench should adequately control underseepage.

Construction Materials

Sufficient construction materials for a homogeneous fill-type embankment section are within 3 air miles of the damsite as shown on Plate 38, "Location of Construction Materials, Larabee Valley and Eaton Damsites".

Impervious to Semi-pervious. Three alluvial terrace levels with a total thickness of over 50 feet have been preserved in Larabee Valley. These terraces are composed of weakly consolidated lenses of gravel, sand, and silt; they commonly dip gently to the west. Only the weathered, upper zones of the terraces appear suitable for use as impervious to semi-pervious fill. Considering an average depth of 12 feet of usable impervious material, about 4 million cubic yards of terrace deposits are available in Larabee Valley.

The weathered terrace material appears to be a gravelly sand with low to moderately plastic fines. The gravel sizes, about 25 percent of the deposit, consist of rounded to sub-angular pebbles of sandstone, greenstone, quartz, chert, and schist, all derived from the Franciscan group.

Two samples were collected from the terrace deposits in Larabee Valley in an earlier investigation and tested for compaction. A compactive effort of 25,500 foot-pounds gave dry densities of 113 and 120 pounds per cubic foot, respectively.

An additional source of impervious material can be readily obtained from the numerous landslides near the damsite. The suitability of these materials are not known, but unlimited quantities are available.

Pervious-Filter Drain. Adequate quantities of filter drain materials occur along the Van Duzen River near Dinsmores. Commonly the deposit is a loose, fine, silty sand overlain by rounded to flat gravels. The sand sizes are clean and do not contain excessive amounts of mica. All materials are derived from the Franciscan formation.

Riprap and Aggregate. Limited quantities of riprap materials are available locally. Riprap can be obtained from isolated greenstone plugs and sandstone outcrops.

Suitable-appearing aggregate is deposited along the Van Duzen River upstream from Dinsmores and has been briefly described above. Aggregate materials are scarce along this reach of the South Fork Van Duzen.

Conclusions

1. Preliminary investigation indicates a fill dam greater than 200 feet in height appears questionable until the following information is known and evaluated.

   a. Depth and type of bench materials on the right abutment.

   b. Characteristics of the fault zone on the right abutment.

   c. Characteristics of the shear zones in the channel area.

   d. Extent and depth of landslide and slopewash material in the foundation area.

2. Sufficient quantities of construction materials for the fill dam of preliminary design are within 3 air miles of the damsite.

3. Cursory examination indicates that a chute spillway located on the upper left abutment and a diversion tunnel located through the lower right abutment will be satisfactory.

4. Landslides may occur in the reservoir area.

Recommendations

It is recommended that there be:

1. Detailed geologic mapping of the damsite on a topographic map of suitable scale (1 inch = 200 feet).

2. Exploratory drilling and geophysical investigation of geologic problem areas discussed under Conclusion No. 1.

3. Auger drilling and testing of impervious material.

4. Investigation of pervious, aggregate, and riprap materials.

5. Geologic mapping of reservoir area with emphasis on extent and characteristics of landslides.

Larabee Tunnel

The proposed Larabee Tunnel connecting the Larabee Valley and Eaton Reservoirs is located in T1N, R5E, HB&M, Humboldt County. The entire alignment is covered by the USGS 15-minute Blocksburg quadrangle, with a scale of 1:62,500 and a contour interval of 100 feet.

Access is provided by State Highway 36, which passes through both portal locations, and by poorly kept dirt roads which cross the proposed alignment.

Description of Project

The proposed tunnel has approximate portal elevations of 2,500 at Larabee Valley Reservoir and 2,450 at the Eaton Reservoir, and will be 13,400 feet long. In the preliminary analysis cost estimates were made for 10-, 15-, 20-, and 25-foot diameter tunnels. Optimum tunnel dimensions have not been computed at the time this report was written. (As an alternative to this tunnel, a 2.5-mile pipeline connecting Eaton and Larabee Valley Reservoirs has been adopted in Bulletin No. 136 as shown on Plate 1.)

Geology of Tunnel Line

The entire Larabee tunnel alignment lies in rock units of the Central Franciscan belt. The geology in this region is extremely complex -- virtually all rock units crop out in discontinuous lense-shaped bodies surrounded by deep accumulations of soil, slopewash, and landslide material. The tunnel area has experienced very strong deformation as evidenced by extensive folding and faulting of the Franciscan rock units. The discontinuous nature of the rock types and the extreme variance in relative competence has given an extremely disordered, nearly chaotic appearance to the local geology following several periods of deformation. The regional structure in this area trends about N20W and is readily reflected on aerial photographs and in the topography. Sedimentary strata have generally N15° to 40°W strikes and variable dips.

The predominant rock types are graywacke sandstone (60 percent) and black, thinly bedded shale (20 percent), accompanied by chert lenses, greenstone, conglomerate, various metamorphic rocks, and serpentine. Distribution of these rock units along the alignment is shown on Plate 36, "Geologic Map and Section, Larabee Tunnel".

A major fault zone crosses the proposed tunnel line about 2,500 feet south of the Van Duzen portal. This zone of weakness was estimated to be about 5,700 feet wide, and will constitute a major tunneling hazard. The fault zone is characterized by extreme shearing, crushing, and slickensiding of the rock units, and contains a great variety of rock types including sandstone, shale, greenstone, serpentine, chert, glaucophane schist, and various exotic metamorphic rocks such as amphibolite and garnet-amphibole schist. As is typical of large Franciscan faults, this zone contains blocks or lenses of relatively undeformed rock, which however, are surrounded by intensely sheared material. Extensive sliding has developed over the weak material and a detailed study of potential tunneling difficulties in this area was not possible.

Another less pronounced fault zone was mapped about 1,500 feet north of the South Fork Van Duzen portal. This zone is 500 feet wide and has a N15W trend. Numerous small bodies of deformed, crushed serpentine were found within this zone and are expected to be present at depth. Tunneling conditions will be further complicated by deep weathering and alteration of the crushed rock along this zone. The depth of cover is only 100 feet and sheared rock weathered to weak clayey material may be encountered by the tunnel.

Numerous small shears and faults were noted in the tunnel area. These zones of weakness are generally discontinuous and may often be confined to incompetent rock units such as shale or serpentine. Minor shears are often found near bodies of resistant rock such as chert and greenstone and appear to have been caused by the crushing of weaker material against harder rock in the process of regional deformation. Owing to the heterogeneous nature of the Franciscan group in the tunnel area, these small shears are quite numerous and will cause considerable tunneling difficulties.

Folding in the tunnel area is complex and is difficult to interpret owing to poor exposures, discontinuity of rock units, and extensive colluvial cover. Based on reconnaissance work, the tunnel will cross three large folds -- two anticlines and one syncline. The axes of the folds trend N35°-40°W and cross the alignment on an angle of 60° to 70°.

Tunneling Conditions Zones

In the course of the reconnaissance geologic investigation the proposed tunnel line was divided into two tunneling conditions zones (see Plate 36) based on the physical properties of the rock as related to tunneling cost. Factors such as the hardness, degree of fracturing, weathering or alteration, stratification, schistosity, degree of shearing and crushing, and presence of clayey gouge were taken into consideration in delimiting the relative tunneling conditions zones.

Terzaghi rock load factors were assigned to each zone in accordance with criteria described in Department of Water Resources Bulletin No. 78, Appendix C, "Procedure for Estimating Costs for Tunnel Construction".

The following table lists the rock conditions and corresponding rock load used in determining tunneling costs.

Estimated Rock Load

Rock load Hp in feet of rock on roof of support in tunnel with width B (ft) and height Ht (ft) at depth of more than 1.5 (B+Ht)

Rock Condition	Rock Load Hp in feet	Remarks
1. Hard and intact	zero	Light lining, required only if spalling or popping occurs.
2. Hard stratified or schistose	0 to 0.5 B	Light support.
3. Massive, moderately jointed	0 to 0.25 B	Load may change erratically from point to point
4. Moderately blocky and seamy	0.25 B to 0.35 (B+Ht)	No side pressure.
5. Very blocky and seamy	(0.35 to 1.10) (B+Ht)	Little or no side pressure
6. Completely crushed, but chemically intact	1.10 (B+Ht)	Considerable side pressure. Softening effect of seepage towards bottom of tunnel requires either continuous support for lower ends of ribs or circular ribs
7. Squeezing rock, moderate depth	(1.10 to 2.10) (B+Ht)	Heavy side pressure, invert struts required. Circular ribs are recommended.
8. Squeezing rock, great depth	(2.10 to 4.50) (B+Ht)	
9. Swelling rock	Up to 250 ft irrespective of value of (B+Ht)	Circular ribs required. In extreme cases use yielding support.

Zone I. Tunneling Zone I contains predominantly graywacke sandstone with shale interbeds. The sandstone beds have an average thickness of 2 to 3 feet and are extensively jointed. The intersection of joints and bedding planes gives the rock a blocky appearance and the average joint spacing was estimated to be about 1 foot. The rock is fine-grained and hard when fresh and has a characteristic greenish-gray color. In weathered outcrops sandstone may become soft and crumbly and has an oxidized reddish-brown color.

Shale interbeds are generally 1 to 3 feet in thickness and are often intensely sheared and fractured. Locally, shale beds up to 20 feet in thickness were observed containing blocks of graywacke.

Numerous chert lenses were mapped near the outlet portal and are scattered throughout the tunnel area. These lenses are 10 to 50 feet thick and consist of hard, brittle, thinly laminated red to green chert and are commonly veined by secondary silica along old fractures.

Minor rock types in Zone I consist of a few lenses of conglomerate, greenstone, and glaucophane schist.

The tunneling conditions in Zone I are expected to be generally very blocky and seamy with thin zones of completely crushed rock. Overbreak will be heavy especially in thinly bedded shale and in intensely jointed rock. The entire zone will require steel support and about 10 percent of Zone I will need invert struts to compensate for lateral pressures.

Water inflows should be generally moderate; however, high local inflows can occur in interconnected fractures and in minor shear or fault zones. An area of potentially high water inflow is indicated on the geologic section just south of the major fault zone (see Plate 36). The geologic structure in this area appears to be an irregular syncline which is cut by a major fault zone. The fault may locally act as a barrier to ground water movement and considerable quantities of water can be stored in interconnected open fractures and minor shears which are usually found near major faults.

Rock load, support requirements, and overbreak are expected to vary erratically throughout the entire zone.

Summary of Tunneling Zone I

Rock Condition	Rock Load Hp in feet	Percent of Zone
5 Very blocky and seamy	0.725 (B+Ht)	90
6 Completely crushed - some lateral pressures	1.10 (B+Ht)	10

Zone II. Tunneling Zone II includes the two fault zones crossed by the proposed tunnel and represents extremely hazardous tunneling conditions. Both fault zones are characterized by intense shearing and fracturing of the rock along wide, poorly defined belts. The fault zone contains a striking collection of highly diverse rock types which appear to have been jumbled and disoriented during the deformation process. Rock types found in the fault zones are sheared sandstone and shale and lenses of serpentine, greenstone, basic and ultrabasic intrusives, and various metamorphic rocks such as glaucophane, actinolite, and garnet schists. Lenses of schist and greenstone are generally very hard and appear to "float" in a matrix of crushed gougy rock. Small bodies of sheared to completely crushed, "soapy" serpentine are scattered throughout the fault zones.

Numerous small springs were mapped within the fault zones indicating that the rock is at least partially permeable and may store a great volume of ground water. Serious ground water inflows under considerable hydrostatic pressure may occur within the major fault zone under a depth of cover of over 1,000 feet (see section, Plate 36). No hot waters were found; however, two of the springs near the tunnel line contained H_2S and sulphorous waters could be encountered at depth. Based on this information it was estimated that roughly 50 percent of the Zone II material will be excavated under wet heading conditions.

Tunneling conditions in Zone II should generally be completely crushed with minor zones of very blocky and seamy rock. Tunnel excavation will have to be by the multiple drift method except for small diameter bores. Invert struts and close blocking will be required to counteract any lateral pressures and to prevent progressive overbreak in sheared gougy material.

Summary of Tunneling Zone II

Rock Condition	Load Factor Hp in feet	Percent of Zone
6 Completely crushed	1.1 (B+Ht)	60
5 Very blocky and seamy	0.725 (B+Ht)	40

Fifty percent of the zone will be under wet heading conditions.

Conclusions

1. The proposed Larabee Tunnel lies in an area of intense geological deformation and will cross two major fault zones. Serious tunneling hazards are anticipated in the fault zones including high overbreak, sheared gougy rock, high water inflows, and moderate squeezing pressures.

2. Steel support will be required for the entire tunnel line and invert support will be needed in 60 percent of the fault zone material.

3. Lining will be required throughout the entire tunnel.

4. As mentioned previously, ground water inflows will be moderate to high, especially so in intensely fractured, sheared rock.

5. Several sulphurous springs were noted within fault zone material and mildly sulphurous ground water is anticipated locally at tunnel grade.

6. Adequate quantities of concrete aggregate for use in the lining operations are located within 1 mile of the outlet (northern) portal.

Recommendations

1. Further engineering geologic studies of the Larabee Tunnel line will require a detailed geologic map with a scale of at least 1 inch = 1,000 feet. Such a map will permit a more detailed evaluation of the surface geologic conditions and tunneling conditions could be projected to invert elevation with a greater degree of certainty.

2. Dozer trenches and diamond drill holes located within the fault zone will provide valuable information about the nature of the sheared material and will permit a more accurate evaluation of the weak zones. Outcrops in the sheared rock are virtually nonexistent and very little is known about this material.

3. Springs in the tunnel area should be sampled and tested to determine the presence of any chemicals which may be deleterious to the concrete lining and steel support.

Eaton Damsite

Eaton damsite on the Van Duzen River lies in Sections 5 and 8, T1N, R5E, HB&M. The site is located about 1.5 miles west of the community of Dinsmores and is easily accessible via State Highway 36 which passes over the left abutment.

The site is covered by the USGS 15-minute Blocksburg quadrangle with a scale of 1:62,500 and a contour interval of 100 feet. Reconnaissance geologic mapping was done on a Department of Water Resources map with a scale of 1-inch = 500 feet and a contour interval of 20 feet.

Description of Project

The proposed Eaton Dam is part of the Mad-Van Duzen diversion project which also includes Larabee, Enlarged Ruth, Butler Valley, and Anderson Ford dams, Van Duzen Pipeline, and Mad and South Fork Tunnels.

The preliminary design calls for an earth core and gravel shell dam. A concrete lined chute spillway designed for 85,000 cfs will be located across the right abutment, terminating in a stilling basin.

Three crest elevations at 2,565, 2,625, and 2,725 were considered in the preliminary analysis. Preliminary statistics for the three heights considered are presented below.

Preliminary Statistics

	Crest Elevation		
	2,565	2,625	2,725
Normal water surface elevation	2,540	2,600	2,700
Maximum water surface elevation	2,560	2,620	2,720
Minimum water surface elevation	2,405	2,405	2,405
Height of dam in feet	235	295	395
Total volume of fill in cubic yards	2,160,000	3,200,000	7,810,000

Geology of the Site

Eaton Damsite lies within the central belt of the Franciscan group, which is characterized by the diversity and discontinuity of the rock units and intense deformation as evidenced by extensive faulting and shearing. The foundation rock consists of shale, sandstone, chert, greenstone, and low grade metamorphic rock including slate and glaucophane schist. Outcrops are poor, expecially so on the left abutment, and are covered by colluvium and landslide debris. A major fault zone crosses the stream channel about 300 feet downstream on the toe of the dam. The rock at the site is intensely fractured and locally sheared, probably owing at least in part to the close proximity of a major zone of weakness. The site is situated in a steep, narrow canyon and although the slopes are relatively stable there is a considerable accumulation of talus and slopewash at the base of the slopes. Geology of the site is shown on Plate 37, "Geologic Map and Section, Eaton Damsite".

Foundation Conditions

Right Abutment. The right abutment is formed by a narrow plunging ridge which has a relatively even slope within the fill limits of the proposed structure. The average abutment slope is roughly 35° to elevation 2,700 or about to the crest of the highest dam. Above this elevation there is a narrow saddle which provides a topographically advantageous spillway location. The lower 50 feet of the abutment slope is very steep and may locally have a slight overhang.

Outcrops are nearly continuous near the channel and are prominent over the entire right abutment, mantled locally by shallow slopewash and talus. Areas of deep slopewash and landsliding are located both up- and downstream from the site.

The abutment is underlain by greywacke sandstone with shale interbeds, chert, and greenstone (see Plate 37). The lower abutment slope is formed predominantly by sandstone and shale which has a strike roughly parallel to the stream channel and dips into the abutment at angles ranging from 30 to 40 degrees. The upper right abutment is underlain by a dense, dark colored volcanic rock, probably of intrusive nature. The attitude of the sedimentary strata is such that it tends to form a rather stable slope with only minor rockfalls and talus wedges. In contrast, the left abutment, which is near dip slope, exhibits considerable instability partially related to sliding and creep along the dip.

All rock units are extensively jointed, with an average fracture spacing of about 6 inches on the surface. The minor joints are probably closed within 5 feet in depth and only the major, more widely spaced fractures remain open. No attempt was made during reconnaissance mapping to define any preferred joint orientations or to determine any fracture patterns. In general there is a prominent joint set trending roughly N50W, which seems to be related to the major fault zone located a short distance downstream. Considerable shearing and faulting was observed in this direction, especially in the downstream toe area where the rock is intensely deformed and contains seams of clayey gouge. The deformation apparently has occurred along a fault which crosses the channel and continues into the left abutment near the colluvial cover (see Plate 37).

Foundation conditions on the right abutment appear to be overall quite good and no unusual construction difficulties are anticipated. The fault gouge in the downstream toe area will have to be overexcavated and backfilled with selected material; however, as no great loads will be applied to the foundation at this point and since the rock surrounding the sheared portions is competent, no stability problems appear to be present in this area.

Foundation preparations on the right abutment under the impervious section will consist of removal of all the colluvium, talus, and loose rock, in addition to about 5 feet of deeply weathered and jointed bedrock -- an average overall depth of 8 feet.

Stripping under the pervious section will require removal of 3 feet of overburden material. Some hardrock shaping will be required at the base of the abutment in order to provide a smooth surface for placement of fill.

All overburden and loose rock excavation will be by common methods. Some blasting will be required in the cutoff section.

Channel. The channel section is 60 to 75 feet wide and has a relatively gentle gradient at the site. The gradient steepens rapidly a short distance downstream in highly deformed fault zone material.

The channel is covered with stream alluvium and large boulders of chert and other resistant rock types derived primarily from the left abutment. Through mass wasting and landsliding the right side of the channel is relatively clear and there are good outcrops of sandstone, shale, and chert at the base of the abutment. There are no outcrops on the left side of the channel nor are there any definite exposures in the streambed proper. The average depth of alluvium is estimated to be 10 feet. Scour or pot holes formed by erosion of weaker rock units may be present below the alluvium and could attain a depth of 20 feet.

Foundation stripping under the impervious section will necessitate excavation of 10 feet of alluvium and about 3 feet of bedrock. All alluvium should also be removed from the pervious section to permit inspection of underlying bedrock.

Seams of sheared gougy material and irregular pot holes should be overexcavated and filled with concrete under the impervious section. Dental concrete work is expected to be of very minor importance.

Left Abutment. The left abutment has a steep irregular slope, cut by a ravine upstream from the proposed dam axis. The flow of water in this minor ravine is consistently quite high and appears to be perennial except probably in very dry years. The amount of water does not seem to be compatible with the limited drainage area available for this creek and may in part be supplied through ground water seepage along the intensely sheared and brecciated fault zone material which was mapped in the drainage area. The creek should be diverted during construction and operation of the Eaton project to prevent erosion of the embankment material. The location of a small diversion structure and a pipeline are diagrammatically indicated on Plate 37.

Very few scattered outcrops were mapped on the abutment slope. These consist of lense-shaped knobs of resistant rock, surrounded by colluvium. Nearly all the outcrops are located near the crest of the abutment, with the lower slope being completely covered by talus, soil, and slopewash.

The depth of colluvium was found to be extremely variable and proved to be difficult to estimate without any subsurface exploration. As determined by reconnaissance mapping and backhoe trenches, the abutment can be divided into three distinct areas, based on the depth of colluvium. The upper and the central downstream portions of the slope are covered by relatively shallow overburden ranging from 5 to 15 feet and averaging about 10 feet overall. The up- and downstream toe areas and the central portion of the lower abutment slope are underlain by very deep colluvium and landslide debris. An average depth of 25 feet was estimated in these areas only on surficial geologic observations.

Areas of deep colluvium up- and downstream from the site should be considered as potential slide hazards during the operation of the reservoir and may cause damage to the embankment. Some active sliding was observed in the downstream toe area and a very large active landslide is located just downstream of the site. Some excavation will be required both up- and downstream from the embankment to alleviate the danger of sliding. Extensive subsurface exploration is needed for a quantitative estimate of excavation required. Colluvium should also be tested for possible use in the dam sections.

The upper left abutment was explored during June 1963 by 22 backhoe trenches which were located on an abandoned logging trail (see Table 22). The trenches were on the average 12 feet long, 9 feet deep, and 3 feet wide. A precise location of the trenches was not possible owing to a lack of ground control points on the topographic map and a relatively small scale (1-inch = 500 feet).

Thirteen of the 22 trenches encountered weathered bedrock and proved to be extremely valuable in the interpretation of foundation conditions and average stripping depths. Based on surficial geologic mapping and exploration results, the southwest portion of the abutment appears to be underlain by intensely sheared and brecciated rocks which can be considered to be the eastern border of a major fault zone which crops out downstream from the site. The trend of the deformed zone is roughly N55 to 60W (see Plate 37). A more accurate determination of the extent and foundation characteristics of this zone was not possible because of limited time and lack of outcrops. This zone consists of a series of NW trending shear zones which are separately by intensely fractured and crushed but more competent rock. A prominent gouge zone was penetrated below the colluvium in several trenches, and represents a major foundation defect. This zone consists of a plastic, bluish grey clayey gouge with slikensided tabular chips or shards of shale, gloucophane schist, greenstone, and chert. Occasional boulders and shear pebbles of resistant rock were found within the gouge. This fault zone appears to be about 100 feet wide and represents a zone or lense composed predominantly of black fissile shale which has been crushed and partially altered to gloucophane schist. Any further investigation of the Eaton damsite will require a detailed study of this zone as it may prove to be a deciding factor in determining the feasibility of the site.

Foundation preparation on the left abutment will consist of removal of all colluvium and landslide debris accumulations in addition to deep bedrock stripping. The following average figures for abutment stripping should be used only for preliminary planning work owing to lack of reliable sub-surface data. Impervious stripping will necessitate removal of 15 feet of overburden and 15 feet of weathered and fractured bedrock as averaged out over the entire abutment slope. Gouge seams in the major fault zone should be overexcavated and backfilled with concrete and selected fill materials. Seeps and springs will probably require construction of a system of drains as grouting in clayey fault zone materials would probably not be effective. Virtually all abutment stripping should be by common excavation methods.

In addition to stripping under the embankment section, considerable excavation will be required both up- and downstream from the site in potential landslide areas.

Grouting in the cutoff section on the left abutment may not be entirely effective owing to intense shearing and presence of altered clayey gouge in the fractures. The impervious section may have to be extended into the upstream portions of the abutment to form a cutoff blanket. Drainage of the foundation may also constitute a major construction difficulty. A network of drain holes may be required to reduce seepage pressures.

Spillway

A narrow saddle at elevation 2,750 above the right abutment provides a topographically favorable spillway location. Rock types in the spillway cut will be mostly greenstone, sandstone, and some sheared shale lenses. The rock is very deeply weathered and cut slopes will be on the order of 1-1/2:1. The concrete lined chute crosses two areas of deep colluvium and landslide debris. Considerable sliding was observed both above and below the proposed chute and removal of the unstable material above the structures may be required.

The stilling basin is located in a highly unstable area. Numerous landslide scarps were observed near the channel elevation and a major active slide is located directly across the river. Based on reconnaissance mapping, the bedrock below the colluvium consists of sheared gougy fault zone material belonging to the fault zone uncovered on the left abutment.

An alternative spillway location would be a cut through the narrow ridge above the left abutment that would discharge the water directly on a major slide, underlain by a fault zone. This plan would require a cut about 150 feet deep for the 2,725-foot crest elevation through intensely sheared and fractured rock. Erosion of the landslide by the spill would cause a major debris flow into the river. This could conceivably cause considerable damage downstream, and may obstruct the outlet tunnel.

Diversion Tunnel and Outlet Works

The right abutment provides the most favorable location for a diversion tunnel. Rock types encountered will consist of sandstone, slaty shale, greenstone, and chert. Overall tunneling conditions should be quite good and no unusual tunneling difficulties are anticipated. The outlet portal lies in an unstable landslide area and extensive excavation will be necessary to secure a stable face.

Construction Materials

No exploration or sampling of construction materials has been undertaken for Eaton damsite. Location of the various materials required, based on a reconnaissance survey, is shown on Plate 38.

Impervious Material. An apparently adequate source of impervious fill for the proposed Eaton damsite is located 1/2 to 1-1/2 miles to the east. This material consists of landslide debris and colluvium derived from decomposed, Franciscan rock types within a major fault zone. The average composition is that of a gravelly, clayey silt with abundant angular to subangular rock fragments. Numerous residual blocks and probable outcrops of resistant rock lenses are visible throughout and will require some selective excavation. No samples were obtained during the reconnaissance investigation stage; however, from past experience with similar materials, this source of fill should meet the impervious core requirements.

Pervious Material. A virtually unlimited volume of river alluvium suitable for pervious shell material is located in the Van Duzen River channel 1 to 5 miles upstream from the site. Average haul distance will be about 1-1/2 to 2 miles. The alluvium is composed of unconsolidated sand and gravel derived primarily from Franciscan sandstone. Pebble size material consists of 90 percent sandstone, usually well-rounded with subordinate amounts of slaty shale, schist, chert, and greenstone. Less than 5 percent of the gravel is over 6 inches in diameter. Flat pebbles are relatively uncommon and constitute a minor percentage of the whole deposit. Sand size particles contain a high percentage of potentially unstable shale fragments.

No tests were performed on these materials to date. However, based on surficial examination, the alluvium appears to be well suited for pervious shell zones.

Riprap. A large block of resistant glaucophane schist located 1/2 mile south of the site should provide an adequate volume of good quality riprap.

Conclusions

Based on geologic mapping and backhoe trenching on the left abutment the proposed Eaton damsite cannot be recommended without further foundation studies. At least two alternate sites are located within one mile upstream, but do not appear to be any better suited geologically and will require more embankment material.

Another alternative site -- Forks damsite -- lies about 2 miles west of Eaton damsite just downstream from the confluence of the Van Duzen and South Fork Van Duzen Rivers. This site should be considered for the lower crest elevation plans as it would replace the proposed Eaton and Larabee Dams. A dam about 600 feet high would have to be constructed for a crest elevation of 2,565. Cursory geologic reconnaissance indicates that Forks damsite has excellent foundation conditions and should be suited for a high earth core gravel shell dam.

Recommendations

1. A thorough foundation exploration program is needed at Eaton damsite for a proper evaluation of the foundation conditions, especially on the left abutment and in the downstream toe areas which are underlain by sheared, gougy fault zone material.

2. Exploration study should include trenches and pits, diamond drilling, and plate bearing tests to determine the bearing capacity of the weak clayey gouge.

3. Construction materials sources should be sampled and tested to determine the design criteria for the embankment.

TABLE 22

Eaton Damsite
Summary of Backhoe Trench Exploration

Trench Number	Trench Depth Beneath Roadbed	Depth of Roadcut From Normal Ground Surface	Trench Depth From Normal Ground Surface	Depth to Rock From Normal Ground Surface	Rock Types
T-1	8.5	7.0	15.5	15.5	Sheared greenstone and chert intensely altered, fractured and slickensided. Bedrock surface is irregular.
T-2	8.5	6.0	14.5	14.5(?)	Possibly bedrock at bottom.
T-3	8.5	4.0	12.5	9.0	Sheared and fractured chert open fractures filled with clayey gouge.
T-4	2.5	4.0	6.5	---	Refusal - boulders.
T-5	9.5	4.0	13.5	---	All slopewash.
T-6	9.0	5.0	14.0	12.5	Altered greenstone with clay in fractures. Slickensided.
T-7	9.0	2.0	11.0	---	All slopewash - water at 7.0'.
T-8	9.0	4.0	13.0	---	All slopewash.
T-9	8.5	2.0	10.5	8.5	Blue-gray clayey gouge - sheared shale and schist fragments.
T-10	7.5	4.0	11.5	7.5	Blue-gray gouge.
T-11	8.5	3.0	13.5	13.5	Sheared chert and silica shale.
T-12	6.25	7.0	12.35	11.5	Sheared chert and shale.
T-13	9.0	8.0	17.0	14.0	Sheared chert and shale.

TABLE 22 (Continued)

Eaton Damsite
Summary of Backhoe Trench Exploration

Trench Number	Trench Depth Beneath Roadbed	Depth of Roadcut From Normal Ground Surface	Trench Depth From Normal Ground Surface	Depth to Rock From Normal Ground Surface	Rock Types
T-14	9.5	---	9.5	---	Bottom is in residual clayey soil - probably near bedrock surface.
T-15	9.0	2.0	11.0	7.5	Blue-gray gougy shale partially altered to glaucophane schist.
T-16	7.5	4.0	11.5	---	Brown clayey gouge at 9.5' nearly in place.
T-17	10.0	2.0	12.0	9.0	Sheared gougy shale partially altered to glaucophane schist.
T-18	10.0	2.1	12	---	All slopewash - water at 9.5'.
T-19	8.5	---	8.5	8.0	Sheared shale - gougy.
T-20	10.0	2.0	12.0	---	All slopewash.
T-21	9.0	4.0	13.0	---	All slopewash - water at 7.0'.
T-22	9.0	---	9.0	7.0	Sheared gougy shale.

Note: Trenches were dug on an old logging road which traverses the left abutment.

Trenches 1-4 are located approximately at crest elevation (about 2,700') near axis.

Trenches 5-14 are located diagonally down and across the abutment approximately between elevation 2,600 and 2,500.

Trenches 15-19 are located just above main road near axis.

Trenches 20-22 are located just below main road near axis.

Mad River Tunnel

The proposed Mad River Tunnel is designed to transport the combined releases from the Larabee Valley and Eaton Reservoirs into the Anderson Ford Reservoir. The tunnel is located on the USGS 15-minute Blocksburg and Pilot Creek quadrangles. The inlet portal on the Van Duzen River is located in Section 3, Township 1 North, Range 5 East, HB&M, and the terminating portal on the Mad River is in Section 2, T1N, R5E. The total length of the tunnel line is 0.8 mile and the maximum depth of cover is roughly 650 feet.

The geologic study of the tunnel line consisted of a brief reconnaissance along a recently constructed logging road which nearly parallels the proposed alignment and crosses what was considered a representative section of rock types. No additional geologic mapping was attempted at this time owing to lack of time and a virtualy absence of outcrops or any continuous mappable rock units in the tunnel area.

The tunnel crosses rock types of the Franciscan formation which consist of interbedded greywacke sandstone and black fissile shale. The average strike of the strata is N30W to N40W with an eastward dip ranging from 25° to 65°. No major faults or any significant zones of weakness which may influence the tunneling cost were noted and the tunneling conditions are expected to range from moderately to very blocky and seamy. The following table summarizes the anticipated tunneling conditions for use in preliminary design only.

Summary of Tunneling Factors

Rock Condition	Rock Load Hp in feet	Percent of Tunnel
Very blocky and seamy	0.725 (B+Ht)	50
Moderately blocky and seamy	0.35 (B+Ht)	50

No unusual water inflows should occur during tunnel driving and the entire excavation is expected to be under "dry heading" tunneling.

Additional geologic work on the proposed Mad Tunnel line should include detailed geologic mapping on a topographic map with a scale of at least 1-inch = 1,000 feet and a contour interval of 20 feet. Dozer trenches should be excavated in areas suspected to be underlain by weak rock.

Anderson Ford Damsite

Anderson Ford damsite is located on the Mad River in Section 16 and 17, T2N, R5E, HB&M in Humboldt County. The axis is approximately 0.5 mile downstream from the confluence with Pilot Creek. Topographic coverage of the site is provided by the USGS Pilot Creek quadrangle, which has a scale of 1:62,500 and a contour interval of 50 feet.

The site is accessible by State Highway 32, from Fortuna or Red Bluff, to about 1.4 mile west of Dinsmores, then by about 6 miles of private dirt road which traverses the left stream bank at the site.

Purpose and Scope

A dam at the site would divert water from the Mad River through the South Fork Tunnel into Eltapom Reservoir on the South Fork Trinity River. Heights ranging from 190 to 355 feet have been considered for the dam. The elevation of the channel at the site is about 2,075 feet.

The purpose of this investigation was to determine geologic conditions near the site, and to evaluate foundation conditions for a fill-type dam and structures appurtenant to it. In addition, a survey was made to locate suitable materials from which the dam could be constructed. The investigation was accomplished during a period of about 5 man-days. Geologic mapping of the foundation was performed on a base map with a scale of 1:12,000, made from an enlargement of the 15-minute Pilot Creek quadrangle. Geologic interpretation is based on superficial information only.

Previous Investigations

Previous geologic investigations at the site consist of a brief examination and a reconnaissance outline report in 1959. The U. S. Bureau of Reclamation made a geologic reconnaissance of the site and prepared a short unpublished report in about 1957.

Geology of the Site

Bedrock at the site consists of interbedded sandstone and slaty shale of the Franciscan formation as shown on Plate 39. "Geologic Map and Section, Anderson Ford Damsite". The sandstone, which comprises an estimated 70 to 80 percent of the foundation, is gray, usually fine-grained, well cemented, and moderately hard. The sandstone beds vary in thickness from a few inches up to several feet. The shales are dark gray to black, thinly bedded, moderately well cemented, and very fissile. They occur in units which have a maximum observed thickness of about 20 feet, but the average thickness is probably less than 2 feet. Quite often the units are intensely fractured and show shearing and slickensides, but in only a few places were they observed to be completely crushed or to contain a large amount of clay or gouge.

In the left edge of the channel, the beds strike N5°W to N30°W, nearly parallel to the channel, and dip 55° to 90°SW, or into the left abutment. In the right channel and on the right abutment, the beds strike essentially in the same direction, but dip to the northeast, into the abutment, at 60° to 80°. The river channel apparently follows the crest of a sharp anticline from slightly below the confluence with Pilot Creek to a point downstream of the axis. The anticline has many small folds superimposed upon both limbs. Some of the folds are slight, and others are sharp and tight. Most of the folding has taken place in the weaker, more incompetent shale beds, and they are often extremely contorted. The thicker and stronger sandstone beds adjacent to the contorted shale beds are often only slightly folded; however, the thick sandstone beds are sometimes folded so tightly that the limbs of the fold are nearly parallel.

Jointing and fracturing varies from slight to heavy. The shale is much more broken and fractured than the sandstone, and will require slightly deeper stripping. The predominate joints strike about N70°E to nearly E-W, perpendicular to the channel, and dip north or downstream at about 30° to 75°.

Foundation Conditions

The left abutment has a slope of about 1.8:1. Bedrock is generally not exposed on the abutment as it is obscured by a thick accumulation of colluvium. Gullies show that the colluvium is often in excess of 20 feet thick. Soil creep and minor slides are common on the abutment, but they are believed to be superficial and probably do not extend into bedrock. Outcrops upstream in the channel, and rock fragments in the colluvium, indicate that the abutment is underlain by interbedded sandstone and shale. The beds dip steeply into the abutment.

The most important structural feature on the left abutment is a shear zone about 50 to 75 feet wide. It is exposed in the channel near the confluence with Pilot Creek, but it is obscured by colluvium in the abutment area. Its location is suggested by small slides and topography, and it appears that the shear diverges from the stream and occurs progressively higher on the abutment in a downstream direction. Its presumed location is shown on Plate 39, but subsurface investigation will be needed to accurately outline it. Where exposed in the channel, the zone is 50 to 75 feet wide and contains crushed and sheared fragments of shale and sandstone but relatively little gouge and clay.

A dam 355 feet high at the original axis selected would probably overlie the shear zone near the crest of the dam. A lower dam, or a high dam downstream at the location shown on Plate 39, would probably not encounter the zone.

Stripping on the left abutment will consist of removing the colluvium, slide material, and part of the weathered rock. The slides and colluvium are estimated to average about 20 feet in thickness on the abutment. For a dam 350 feet high, an additional 5 to 10 feet of weathered rock should be removed beneath the rockfill zones and about 20 feet of weathered rock should be removed under the cutoff. An estimated 50 percent of the stripped material could be salvaged for use as semipervious fill.

The right abutment has an average slope of about 1.3:1. Bedrock is well exposed up to a slight break in slope about 200 feet above the channel, and comprises about 80 percent of thick-bedded sandstone with interbedded slaty shale. The beds dip steeply into the abutment. Colluvium overlying bedrock is quite thin up to the break in slope, but it thickens considerably above the break. Stripping will consist of removing the colluvium and part of the weathered rock. Up to the break in slope, the colluvium is estimated to average about 5 feet in thickness and above the break, about 15 feet. The collivium, and approximately 3 feet of weathered rock below the break in slope, and 5 feet above, should be removed beneath the rockfill sections of the dam. An estimated 10 feet of weathered rock below the break and 15 feet above should be stripped beneath the cutoff. An estimated 50 percent of the stripped material could be salvaged for use as semipervious fill.

The channel is approximately 75 feet wide and contains small, relatively shallow deposits of coarse gravel and boulders. Bedrock is well exposed, and is usually only slightly weathered. Stripping will consist of removal of the gravels and a slight amount of weathered rock. Considerable shaping of resistant sandstone beds will be required to eliminate overhangs beneath. The average thickness of the gravels is estimated to be about 10 feet, but occasional deposits may be as much as 25 feet thick in potholes. The gravels are too coarse for use as transition material, but they could be utilized in the rockfill sections. An estimated 6 feet of weathered rock should be removed beneath the cutoff zone. Essentially no weathered rock will need to be removed beneath the rockfill sections.

The following table summarizes the estimated stripping required for a rockfill dam 350 feet high.

Left Abutment

Cutoff

20 feet of colluvium

15 feet of weathered rock

Rockfill sections

20 feet of colluvium

5 feet of weathered rock

Right Abutment

Channel to 200 feet above Channel

Cutoff

5 feet of colluvium

10 feet of weathered rock

Rockfill sections

5 feet of colluvium

3 feet of weathered rock

Above 250 feet above channel

Cutoff

15 feet of colluvium

15 feet of weathered rock

Rockfill sections

15 feet of colluvium

5 feet of weathered rock

Channel

Cutoff

10 feet of coarse gravels

5 feet of weathered rock

Rockfill sections

10 feet of coarse gravels

The strike of the rock units (parallel to the channel) is unfavorable in regard to leakage through the foundation. Also, the crest of an anticline is usually a zone of tension, and open joints would normally be expected to exist. However, the anticline is tight, other folds are superimposed on it, and it appears that any open joints or bedding planes have been recompressed and closed. A grout curtain of moderate depth should prevent leakage. It is estimated that the grout take will be moderate.

Spillway

The spillway should be located on the right abutment because of the shear zone on the left abutment. It may be desirable to utilize the ravine slightly downstream from the toe for a get-away channel.

Excavation in the spillway below a depth of about 30 feet will be in hard, fresh rock and slopes should be stable at about 0.5:1. An estimated 75 percent of the fresh rock could be salvaged for use in the rockfill sections of the dam. Slopes in the overlying colluvium should be about 2-1/2:1, with berms at the rock contact.

Diversion Tunnel and Outlet Works

If a tunnel is needed for diversion and outlet, it should be located in the right abutment. Rock encountered by a tunnel on the right abutment would be about 80 percent sandstone with interbedded slaty shale. Rock load is estimated to be about 0.35 B+H. The tunnel should be fully lined.

Construction Materials

Impervious Material. The only source of impervious materials investigated during this study consists of landslide debris and slopewash derived from weathered and altered Franciscan rock types. Three potential borrow areas, I-1, I-2, and I-3, shown on Plate 40, were noted within a 2-mile radius of the proposed site. Their combined estimated volume is well in excess of the requirements for the dam.

The potential borrow area I-1 is characterized by irregular grass covered slopes cut by numerous minor gullies. Landslide scarps, creep ripples, seeps, springs, and sink holes indicate that this is a large scale earthflow-type landslide. Outcrops, or large residual blocks and boulders of resistant rock types, mainly sandstone, are scattered throughout, indicating that the bedrock surface is irregular and that selective excavation will be required.

The average usable thickness of material is estimated to be about 10 feet after removal of 2 feet of surficial organic material. The total thickness of the slide debris was observed in only one gully, where it was 15 feet thick. The area is underlain by sheared Franciscan sandstone. The soil is a brown-gray to bluish-gray clayey silt with numerous angular sandstone chips. Extensive sampling and testing is needed to determine the embankment characteristics of this material.

Borrow areas I-2 and I-3 should provide impervious material similar to that in I-1.

Rockfill and Riprap. The only source of rockfill and riprap investigated during the reconnaissance study is located about 1 mile southeast of the site in the canyon of Pilot Creek (see Plate 40). The rock is massively bedded Franciscan graywacke sandstone, and appears to be present in sufficient volume for the proposed rockfill dam.

The sandstone is fine-grained, hard, moderately jointed, and forms continuous cliffs up to 600 feet above the channel. Shale lenses and interbeds constitute less than 10 percent of the entire rock mass. One 100-foot-thick shale and sandstone lens was observed about 350 feet above the channel. This zone of poor quality rock would have to be wasted during quarrying operations. The remainder of the shale is scattered throughout the sandstone body in thin interbeds and would probably be removed with quarry fines.

The strike of the beds is generally N30° to 70°W, with dips ranging from 50° to 70°E. Local reversals of attitude occur, indicating some sharp isoclinal folding. The most prominent joint sets are both parallel and normal to the strike.

The sandstone body is truncated upstream by a fault which continues northwest, parallel to the course of the Mad River. The fault is well above the crest elevation of the proposed dam.

Filter Material and Aggregate. No adequate source of gravel for construction of filters and for use as concrete aggregate was located near the damsite. Gravel bars along the Mad River are generally small and shallow, and consist mostly of coarse gravels with many large boulders. Sand and gravel will have to be imported from the channel of the Van Duzen River, an airline distance of 4 miles.

Conclusions

1. The site is suitable for a rockfill or earthfill dam 350 feet in height.

2. Except for filter and aggregate material, sufficient construction materials, believed to be of suitable quality, are available within 2 air miles of the site. Stream gravels for filter or aggregate are available within 4 air miles.

3. Leakage around the dam will not be a problem, provided a grout curtain is constructed beneath the dam. The grout take is expected to be moderate.

4. The spillway should be located on the right abutment.

Recommendations

1. The foundation should be drilled to determine the depth of the colluvium, the depth of weathering, and the adverse conditions which may exist along the shear zone.

2. Exploration and testing should be performed to determine the quantity and characteristics of the material in the proposed impervious borrow areas.

3. A test quarry in the sandstone rock source is recommended to determine the size and gradation of the blasted rock. Also testing should be performed to determine its strength and durability.

South Fork Tunnel

The location of the two alternate tunnel alignments connecting the Anderson Ford Reservoir and the Eltapom Reservoir on the Mad and South Fork Trinity Rivers is shown on Plates 41 and 42. These are the Pilot Creek and Sulphur Glade alignments. Both alignments are covered by the Pilot Creek, Hyampom, and Blocksburg 15-minute USGS quadrangle maps.

The tunnel lines traverse a rugged, mountainous area and access is provided only by a few poorly maintained logging roads and fire trails. The inlet area of the Pilot Creek alignment can only be reached on horseback over U. S. Forest Service maintained trails.

Description of Project

The proposed tunnel would convey the combined flow from reservoirs on the south Fork Van Duzen, Van Duzen, and Mad Rivers into the Eltapom Reservoir on the South Fork Trinity River. A power drop of about 700 feet is planned in the South Fork Trinity Canyon.

Two alternate alignments were considered during the reconnaissance stage of the geologic investigation. The northern, or the Pilot Creek alignment shown on Plate 41, has the intake portal in Section 22, T2N, R5E, HB&M, and the outlet is located in Section 14, T2N, R6E, HB&M. The southern, or the Sulphur Glade line, shown on Plate 42, has the intake portal in the Mad River Canyon, Section 8, T1N, R6E, HB&M.

The intake and outlet portals are roughly at elevation 2350. The total lengths for the north and south alignments are 6.9 and 4.7 miles, respectively. The final selection of tunnel alignment will depend on the elevation of the minimum water surface of the Anderson Ford Reservoir on the Mad River.

The optimum tunnel dimensions have not been computed at the time of this writing.

Previous Work

The Sulphur Glade alignment was studied in considerable detail in 1958 and a Masters thesis (University of California, Berkeley) based on this study was written by L. V. Girard. The Pilot Creek alignment has not been studied prior to this investigation.

Tunneling Conditions

Bedrock outcrops in the tunnel area are spotty and bedrock where exposed is deeply weathered. Large areas are covered by thick layers of recent landslide debris, soil, and talus. Stream channels generally show the only reliable, relatively fresh rock exposures but the streams are often choked with boulders and slopewash, expecially in areas underlain by weak rock. Geologic mapping proved to be extremely difficult and the interpretation of the underlying tunneling conditions without the benefit of subsurface exploration should be considered a rough approximation at best.

No earthquake epicenters have been recorded in the tunnel region. The Eureka-Humboldt Bay area, 40 miles to the northwest, is one of the most seismically active areas on the Pacific Coast and many damaging quakes have occurred there in historic time. No active faults lie near the tunnels and the seismic risk is suggested only by the effects of severe earthquakes in the Eureka region.

Both tunnel lines cross the South Fork Mountain which forms the divide between the Northern Coast Ranges and the Klamath Mountains geomorphic provinces. The contact between the two contrasting rock type assemblages is a thrust fault which lies near the crest of the South Fork Mountain and brings in contact the sedimentary and igneous rock types of the Franciscan formation (Jura-Cretaceous age) to the west with the older, highly metamorphosed South Fork Mountain schist and the slates, phyllites, and other moderately metamorphosed rocks of the Galice formation (Jurassic). The areal distribution of the geologic units, as well as the structural and the stratigraphic relationships are described in California Division of Mines and Geology Bulletin No. 179 (W. P. Irwin, 1960). The discussion of regional geologic relationships is not considered within the scope of this report and the interested reader is referred to the above-mentioned source.

Description of Rock Units

Franciscan Formation. The Franciscan formation in the tunnel area is represented by rock types characteristic of the central belt unit. All rock units occur in discontinuous lense-shaped bodies, sometimes forming poorly defined belts which contain a high proportion of a certain rock unit and may form a definite tunneling conditions zone.

In general, the Franciscan rocks are unmetamorphosed but are intensely sheared and folded. Several large shears or fault zones were defined during geologic mapping (see Plate 41); however, it is estimated that only a small percentage of the minor faults and shears was disclosed owing to lack of exposures on the weaker zones. In delimiting tunneling conditions zones and assignment of rock load factors, the probability of encountering a higher percentage of poor rock was taken into account.

The Franciscan rocks in the tunnel area are composed predominantly of greywacke sandstone with lesser amounts of shale, siltstone, conglomerate, chert, and greenstone.

The greywacke which comprises about 75 percent of the Franciscan formation is dense dark gray to bluish-green, fine-grained sandstone. Sandstone strata range from a few inches up to 20 feet and average about 3 feet thick. The rock is generally moderately jointed but is usually interbedded with weaker siltstone and shale which has suffered intense deformation. The tunneling conditions in the sandstone will range from stratified to moderately blocky and seamy depending on the thickness of individual strata, the degree of fracturing, and the relative abundance of shale and mudstone interbeds.

Shales and siltstones are found interbedded with graywacke and occur as thin interbeds or as lenses or pods. In general, the shale is one of the weakest rocks within the formation and has absorbed the brunt of the deformation during folding and faulting. Thin shale and siltstone interbeds are often completely crushed and sometimes reduced to a fat clayey gouge. Thicker shale units are more competent and show considerably less shearing and fracturing. Near the contact with the Klamath Mountain province the Franciscan shales and to a lesser degree with siltstones show a pronounced cleavage and some silicification, which appears to be roughly parallel to the thrust fault. No other evidence of metamorphism was noted near the contact.

The average tunneling conditions in the shale will be "completely crushed" and the rock will require immediate support with close blocking because of short bridging time. The shales may be moderately squeezing under great depth of cover such as under the South Fork Mountain, and wet heading tunneling will be encountered where the fracturing is continuous.

Small lenses of chert and greenstone were mapped in poorly defined belts which also contained the clastic rock units of the Franciscan formation. Although the cherts and greenstones are by far the hardest, most resistant rocks of the formation, belts or areas containing a high percentage of these rocks provide very poor tunneling conditions. It appears that during successive periods of folding and faulting the interbedded less resistant rock units were crushed between the highly competent rock, producing lenses of relatively undeformed chert and greenstone in a matrix of completely crushed material.

Tunneling conditions in the chert and greenstone belts will range from very blocky and seamy to completely crushed.

South Fork Mountain Schist. Rock exposures in this unit are very poor and are confined to spotty knobs of gnarled, contorted schist which are surrounded by soil and slopewash. No major canyons traverse this geologic unit owing to its position near the crest of the ridge and no areas of continuous outcrop are to be found near the tunnel alignments. The South Fork Mountain schist thus is the most difficult and least predictable unit in the interpretation of tunneling conditions. The schist occurs in a 2-mile-wide northwest-trending band which is bounded by a thrust fault to the south and a normal fault to the north. The schist is also cut at least by two known major faults -- one parallel to the trend of the unit and one transverse (see Plate 41). Numerous minor shears were noted but could not be traced for any distance because of lack of outcrop. The frequency of these minor zones of weakness will determine to a great extent the cost of tunneling in the schist and a thorough mapping program along the alignments and some trenching is needed for a proper evaluation of the tunneling conditions.

When fresh, the South Fork Mountain schist is a gray to greenish-gray, hard, tough, intricately crenulated rock and may locally resemble a gneiss. Mineralogically, it can be classified as a quartz-muscovite-biotite ranging locally into quartz-muscovite-chlorite schist. The green-colored, chlorite-rich units probably represent metamorphosed volcanic rock interbedded with rock which had originally consisted of clastic sediments. The entire unit has been completely recrystallized and any relic bedding has been obliterated by successive periods of folding and shearing.

Tunneling conditions in the schist unit (outside of the major faults) will range from foliated to very blocky and seamy to completely crushed. The maximum depth of cover will be about 2,900 feet and some squeezing is anticipated in closely fractured, sheared rock. Continuous shears or faults will probably carry considerable volumes of ground water -- about 20 percent of the schist will be excavated under wet heading conditions.

Galice Formation. A series of slates, argillites, foliated sandstone, and low grade schists of the Galice formation crop out near the outlet portal in the South Fork Trinity River Canyon and underlie the proposed penstock and powerhouse foundations for both tunnel alignments.

Near the outlet of the northern alignment the Galice formation consists predominantly of dark-brown to black fissile slate which is only moderately jointed and sheared. Overall this unit should not provide any construction difficulties provided the upper 20 feet of weathered and decomposed material is removed from the powerhouse foundation.

Near the outlet of the southern alignment the Galice is represented by intensely sheared and fractured argillite. The proximity of a major fault appears to be responsible for the incompetent nature of the rock. The southern tunnel line will not penetrate the Galice formation but the proposed powerhouse will be founded on this material.

Faulting

At least five major faults have been defined during the geologic mapping program. These faults appear to represent regional zones of weakness and can be traced for a long distance away from the tunnel alignments. In addition to the major features which are described in detail below, the tunnel area is cut by numerous minor faults and shears, most of which cannot be traced for any appreciable distance and often appear to be confined to weaker rock units such as Franciscan shale.

1. Pilot Creek Fault. The fault zone appears to be 200 to 300 feet wide and is characterized by a series of aligned saddles, topographic breaks, and unstable slopes on the northern side of the Pilot Creek Canyon. The attitude of the fault is N40W with a vertical dip.

Outcrops of fault material in the immediate tunnel area are scarce and consist of slumped exposures of completely crushed sandstone and shale with seams of gray clayey gouge. Good exposures of weak clay-gouge are located about 1 mile north of the alignment along the fault trace. The Pilot Creek fault is truncated by, or disappears under, the South Fork Mountain thrust and does not cross the southern tunnel alignment.

The northern tunnel will cross this fault under 1,500 feet of cover and some very difficult tunneling conditions, including running and squeezing ground, are anticipated. A number of springs and seeps were noted along the fault, indicating that heavy inflows can occur at tunnel grade.

2. South Fork Mountain Thrust Fault. This major structural feature forms the boundary between the Northern Coast Ranges and the Klamath Mountains geomorphic provinces in the tunnel area. This fault intersects both tunnels under almost the maximum depth of cover -- 2,700 feet under the Pilot Creek line and 2,500 feet under the Sulphur Glade line. The most intense deformation, as evidenced by gouge and sheared rock, has occurred in the schist or in the hanging wall of the fault. The underlying Franciscan sandstones and shales are relatively unaffected except for some foliation and silicification near the thrust which has not appreciably decreased the tunneling characteristics.

The thrust fault trace near the crest of the ridge is concealed by slumped soil and landslide debris. A slight break in slope was noted in the fault area and a number of small springs flow at this location.

The attitude of the fault and the width of the crushed zone were determined by indirect observation owing to lack of outcrops. Near the Pilot Creek alignment the thrust appears to dip from 30 to 35° northeastward and the width of the fault zone does not seem to exceed 100 feet measured normal to the strike. The dip of the thrust along the Sulphur Glade alignment is 15 to 25° northeast as determined from observation of the underlying Franciscan shale and sandstone. The width of the fault zone could not be accurately determined but appears to be on the order of 500 feet. The interpretation of the attitude and dimensions of the fault zone can be considerably in error and the projection to tunnel grade is partially diagrammatic. Excavation of trenches across the thrust is needed for a proper evaluation of the tunneling conditions within this zone.

This fault zone will probably create the most difficult tunneling conditions along the proposed alignments. The rock will be completely crushed and probably saturated. High inflows of water under great hydrostatic pressure, as well as squeezing and running ground, should be anticipated within this zone. Grouting ahead of the face will be required to stabilize the rock and to decrease water flows.

3. Hitchock Creek Fault. This fault, the third major northwest-trending fault, lies on the northeast slope of the South Fork Mountain and crosses both tunnel alignments. This fault is identified on Plate 41. The fault zone is covered almost entirely by colluvium and landslide debris and can only be traced through alignment of landslide scarps, springs, and spotty gouge outcrops. The width of the fault zone appears to be about 300 feet and it is estimated to be vertical. Tunneling conditions will be completely crushed with at least 75 percent of this zone under wet heading tunneling. Running and squeezing ground should be anticipated.

4. South Fork Trinity Fault. This fault, the fourth northwest fault, shown on Plate 41, forms the boundary between the South Fork Mountain schist and the Galice Formation. The fault zone is well exposed near the outlet of the Pilot Creek alignment and the attitude and width of this zone have been determined with a reasonable degree of accuracy. The fault strikes N35W and dips essentially vertically. The fault zone at the Pilot Creek Tunnel is 500 to 600 feet wide and consists of crushed, chemically intact to moderately squeezing rock. No excessive water inflows should occur owing to shallow depth of cover. This fault does not cross the Sulphur Glade alignment; however, the powerhouse and a portion of the penstocks will be within the fault zone.

5. Sulphur Glade Fault. This fault, the fifth major fault, strikes N50E and is transverse to the regional northwest structural grain. This fault, shown on Plate 42, belongs to a more recent period of deformation as it cuts across the schist unit and apparently displaces the South Fork Mountain thrust. The average width of the fault zone is about 200 to 300 feet near the tunnel alignment but widens to 1,500 feet at Windy Nip located at the crest of the ridge.

The Sulphur Glade fault does not cross the tunnel alignment but the presence of a fault system nearly parallel to the proposed tunnels should be investigated in detail to detect any other zones of weakness which may follow the tunnel at invert grade for long distances and will create extremely hazardous tunneling conditions.

Portal Locations

Pilot Creek Alignment. The inlet portal is located in a massive sandstone lense and no unusual tunneling problems other than minor scaling are foreseen. The outlet portal lies in deeply weathered slate and phyllite and will require removal of at least 50 feet (vertically) of unstable rock. Rock bolting and wire mesh will be necessary to provide a stable portal face.

Sulphur Glade Alignment. The Sulphur Glade alignment tunnel inlet lies in a highly unstable area overlain by numerous active landslides. The portal selected appears to be in a relatively stable area as determined from aerial photo analysis. Active landslides will have to be crossed by construction and access roads which will require periodic maintenance.

The outlet portal should be located north of Sulphur Glade Creek to avoid an unstable landslide area. No unusual construction problems should be encountered at the recommended location after removal of about 50 feet of soil and weathered rock.

Concrete Aggregate

Alluvial sand and gravel in the Hyampom Valley, 5 and 9 miles from the northern and southern outlets, respectively, can provide sufficient aggregate for the tunnel lining. The Mad River channel in the inlet portals area is narrow and is covered only locally by shallow, discontinuous gravel bars.

Tunneling Zones

Five distinct tunneling conditions zones were recognized during the reconnaissance geologic mapping. These zones represent average tunneling conditions within a formation or an assemblage of rock types. Terzaghi rock load factors were assigned to each zone in accordance with criteria described in the Department of Water Resources Bulletin No. 78, Appendix C, "Procedure for Estimating Costs of Tunnel Construction". Tunneling zones are shown under the geologic sections on Plates 41 and 42.

Zone I. Zone I includes areas underlain by Franciscan sandstone with subordinate interbeds of shale. Tunneling conditions will range from moderately blocky and seamy in massive, jointed sandstone to very blocky and seamy and completely crushed in areas underlain by thinly bedded siltstone and shale.

About 5 percent of Zone I will be excavated under wet heading conditions as described in Bulletin No. 78, Appendix C.

Zone I

Rock Condition	Rock Load Hp in feet	Percent of Zone
Moderately blocky and seamy	0.35 (B+Ht)	50
Very blocky and seamy	0.725 (B+Ht)	40
Completely crushed	1.10 (B+Ht)	10

Zone II. Zone II consists of areas or belts within the Franciscan formation which are underlain by a high percentage of shale or where a high degree of shearing was observed. This zone also includes the belt of chert and greenstone which crosses the Pilot Creek alignment.

Zone II

Rock Condition	Road Load Hp in feet	Percent of Zone
Very blocky and seamy	0.725 (B+Ht)	75
Completely crushed - some lateral pressures under high cover	1.1 (B+Ht)	25

About 20 percent of Zone II should fall under the "wet heading" category.

Zone III. This tunneling zone consists of the South Fork Mountain schist formation. Owing to poor outcrops the properties of this unit with respect to tunneling are virtually unknown and the load factors assigned to this unit should be considered only as a rough approximation.

Zone III

Rock Condition	Rock Load Hp in feet	Percent of Zone
Schistose	0.5 B	50
Very blocky and seamy - some lateral pressures	0.75 (B+Ht)	25
Completely crushed - considerable Lateral pressures	1.1 (B+Ht)	25

About 20 percent of Zone III will be under "wet heading".

Zone IV. This zone consists of the slates and phyllites of the Galice formation which is penetrated only by the Pilot Creek alignment. Tunneling conditions will be schistose or foliated and very blocky and seamy in minor shears and in the weathered zone near the portal. No high water inflows should occur owing to shallow cover.

Zone IV

Rock Condition	Rock Load Hp in feet	Percent of Zone
Schistose or foliated	0.5 B	70
Very blocky and seamy	0.725 (B+Ht)	30

Zone V. This zone describes the tunneling conditions within the major fault zones penetrated by the proposed tunnel lines. The tunnels will cross all major faults under a great depth of cover, with the exception of the South Fork Trinity fault, and extremely hazardous tunnel driving is anticipated.

Closely spaced invert support and circular ribs will be placed throughout the faulted rock.

Rock Condition	Rock Load Hp in feet	Percent of Zone
Completely crushed - considerable side pressure	1.1 (B+Ht)	50
Squeezing rock moderate to great depth	2.1 to 4.5 (B+Ht)	50

Zone V

About 75 percent of Zone V will be "wet heading" tunneling.

Conclusions

1. Geologic mapping in the tunnel area proved to be extremely difficult owing to lack of outcrops, especially so in zones underlain by weak rock. The tunneling conditions as described in this report are often based on sketchy geologic information and will need further, more detailed study.

2. The tunnel lines lie in an area of very strong deformation and tunneling condition overall will be poor.

3. Steel support and concrete lining will be required for the entire length of tunnel. Invert struts and circular ribs will be installed in fault zones and in squeezing rock.

4. Ground water inflows will generally be high with maximum flows concentrated along faults or in closely jointed rock. Grouting ahead of the tunnel face will be required in the proximity of major faults and in sheared rock. Mildly sulfurous springs were noted along two faults and mineralized water may occur at tunnel depth, requiring special cement for tunnel lining.

5. The seismic hazard can be regarded as low.

6. Adequate sources of concrete aggregate are located nearby.

Recommendations

1. Additional detailed geologic mapping is recommended on a topographic map with a scale of at least 1-inch = 1,000 feet and a contour interval of 20 feet.

2. Exploration of the tunnel alignments should include dozer trenches and diamond drilling, expecially along fault zones. Exploration adits directed to penetrate zones of weak rock and to test the tunneling characteristics of representative rock types should be included in a later stage.

3. A comprehensive spring sampling and testing program is recommended to determine the chemical composition of the ground water and to detect any sources of water deleterious to the concrete lining.

TABLE 23

GEOLOGIC CHARACTERISTICS OF DAMSITES

Mad and Van Duzen Rivers

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
NE 1/4 Sec.17, T1N,R6E,RB&M	Ranger Station	Mad River	Right Abutment -- The right abutment is underlain by about 35' of overburden and slide material. Beneath this is fractured black shale. Channel Section -- Fresh, jointed sandstone is exposed over most of the channel area, or is overlain by less than 3' of alluvium. Left Abutment -- The left abutment is underlain by hard, jointed sandstone with a minor amount of interbedded shale. These beds dip steeply into the abutment.	Estimated for an earthfill dam 300' high. Right Abutment -- The stripping estimate is 40'. An estimated 10 million cubic yards of slide would have to be removed or stabilized for the safety of any structure below it. Channel Section -- A minimum amount of excavation is necessary, probably just shaping. Left Abutment -- Stripping is estimated to be less than 10' under the impervious section. Removal of the root zone will probably be sufficient for the remainder of the fill.	1. Location of an end around spillway on the left side of the structure will place it in firm sandstone but will require considerable hardrock excavation. 2. A spillway location on the right will be less favorable as the foundation material is less desirable and the slide is present.		I-Limited amounts of material in the form of residual soils on nearby hillsides. P-Small gravel in ample quantities locally. Spoils, quarry rock. RF & RR-Shortage of good rock in area. Aggregate-Gravel on flats of reservoir area.	Moderate to high	Not recommended owing to poor foundation conditions. (See Anderson Ford alternative).	1. The slide on the right abutment needs special consideration. 2. The saddle between the Mad River and the Van Duzen River should be investigated for leakage and stability. 3. The fault zone which separates the Franciscan and the older schists somewhere on the western slope of South Fork Mt. should be investigated.
NE 1/4 Sec.1, T1N,R5E	County Line	Mad River	Right Abutment -- The right abutment is underlain by intensely jointed greenstone and agglomerate. Bedrock outcrops are surrounded by accumulations of talus and slopewash. Average depth of colluvium is about 10'. Channel Section -- The channel section is about 60' wide. Alluvium depth is about 5'. Left Abutment -- Slopewash and slide debris cover the entire abutment and may extend to depth of 25'. Colluvial debris indicates sandstone and shale at depth.	Estimated for a 200' high dam. Right Abutment -- Impervious section: 10' - 15' of soil, talus and landslide debris. Minor bedrock shaping. Pervious section: 5' of soil, talus and some landslide material. Channel Section -- Impervious section: Cutoff trench 20' deep. Remove all alluvium in addition to minor bedrock shaping. Pervious section: Remove all alluvium. Average 5' in depth. Left Abutment -- Impervious section: An average 20' of slopewash and landslide debris. All common excavation. Pervious section: 5' - 10' of soil and landslide debris.	The most favorable spillway location appeared to be on the right abutment. Depth to rock should not exceed 20'.		I-Landslide debris and colluvium, and weathered shale and sandstone from adjacent slopes will provide ample borrow material. P-Pervious fill must be imported from the Van Duzen channel. RF & RR-No suitable source was located.	Moderate to high	Earthfill.	Extensive foundation exploration and testing is necessary to determine the suitability of slopewash and landslide debris as foundation material.

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
SE 1/4 Sec.34, T2N,R5E	Eight Mile	Mad River	Right Abutment -- The right abutment is underlain by deeply weathered and fractured shales and sandstones, locally mantled by soil and slopewash. Channel Section -- The channel is about 75' wide and is covered by stream alluvium to an average depth of 15'. Left Abutment -- The foundation conditions are similar to those on the right abutment.	Estimated for a 200' high dam. Right Abutment -- Impervious section: Remove 10' average to 15' maximum of soil, slopewash and weathered rock. Pervious section: Remove 5' of slopewash. Channel Section -- Impervious section: Remove all alluvium (averages 15') in addition to 10' of weathered rock to insure cutoff. Pervious section: Remove all alluvium which averages 15'. Left Abutment -- Impervious section: Same as right abutment. Pervious section: Remove 5' of slopewash and landslide material.	The right abutment appears more favorable for a spillway excavation due to the more gentle slope.		I-Deeply weathered shales and sandstones appear well suited for impervious fill and are present in ample quantities. RF-No suitable rockfill source was located in the vicinity of the site.	Moderate to high	Earthfill.	
Cen.Sec.36, T5N,R2E, RB&M	Butler Valley	Mad River	Moderately hard, fractured meta-sandstone with shale beds. Latter are generally sheared. Beds dip moderately into right abutment. These are secondary to several prominent joint sets, however. Landslide on middle and upper left abutment. Shearing minor. Many shears old and recemented.	Light soil mantle on abutments, excepting for slide area on left abutment, where very heavy overburden exists. Moderate rock stripping. Deep channel fill.	Spillway location should be on right abutment to avoid possible slide on left side. Complete lining necessary. Light soil cover over bedrock.		I-Thick mantle of earth, sand, and gravel on Christie Ranch flats within 1 mi. upstream. P-Local stream gravels. Spoils. Gravels from some layers on flats in reservoir area. RF & RR -Some strata of meta-sandstone near site probably would be suitable. Aggregate-Local stream gravels adaptable for use as aggregates despite shale and chert content.	High	Earthfill.	Mad River fault 1-1/2 mi. east of site and others still further east.
NW 1/4 Sec.36, T5N,R2E,HB&M	Lower Butler Valley	Mad River	Right Abutment -- The right abutment is composed of slightly metamorphosed dark mudstone interbedded with streaked gray siltstone of the Franciscan formation. It is hard, brittle, jointed and fractured. The beds strike approximately parallel to the channel and dip into the abutment. Small faults, shears, and flexures are present. Channel Section -- Most of the channel section is covered by stream alluvium of unknown depth. The alluvium overlies mudstone and siltstone similar to that exposed on the right abutment. Left Abutment -- The left abutment is underlain by shaly mudstone and massive, thick bedded sandstone with interbeds of dark, slaty shale. The beds strike parallel to the channel and dip toward the channel. Overburden varies from less than 1' to about 30' in thickness.	Estimated for a 300' high earthfill dam. Right Abutment -- In the foundation area, soil and weathered rock should be stripped to a depth of 6'. In the core trench area, the upper abutment should be stripped to 8' and the terrace area on the lower abutment to a depth of 45'. Channel Section -- In the core trench area, 20' of gravels plus 15' of weathered bedrock must be stripped. Left Abutment -- In the foundation area colluvium should be stripped to a depth of about 10'. Along the core trench colluvium and weathered bedrock should be stripped to a depth of 25'.	The spillway may be located on the right abutment side 2,250' upstream from the axis. It will lie in a saddle of mudstone underlain by sandstone and will require a cut about 100' deep.	A 1,500' long diversion and outlet tunnel is planned through the right abutment about 1,000' upstream from the axis. It will penetrate mudstone and massive sandstone and siltstone. It will encounter shearing and faults and will probably require lining throughout.	I-Terrace deposits downstream 2 - 3 mi. Impervious material in Butler Valley about 1 mi. upstream. P-Stream deposits immediately upstream. Random fill-Sand, gravel and cobbles near Maple Creek 2-1/2 mi. upstream. RR-Franciscan sandstone available at site.	High	Earthfill.	Silting of the reservoir will constitute a problem as indicated by the Sweasey Dam downstream which has silted in at the rate of 1' per year over a 20'year period.

TABLE 23 (continued)

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
Sec.8,T5N, R2E,HB&M	Blue Lake	Mad River	The site is underlain by gray-green, hard, fine grained sandstone of the Franciscan formation. This rock is generally massive and blocky. Jointing is random and widespread. No faults or shear zones were apparent.	Estimated for a fill dam 300' high. <u>Right Abutment</u> -- <u>Impervious section</u>: 15'. Pervious section: 5' The lower .. require hardrock excavation. <u>Channel Section</u> -- <u>Impervious section</u>: A 20' thickness of gravelly alluvium should be removed. Pervious section: Shaping only needed. <u>Left Abutment</u> -- <u>Impervious section</u>: Less than 15' of stripping -- all hardrock. Pervious section: Less than 5' under the pervious section.	Foundation conditions are suitable for a spillway located around the left abutment.		I-Soil, very fine sand and Falor formation north and east of the damsite. P-Channel sands and gravels at site. RF & RR-Salvage from abutment stripping.	Moderate	Earthfill, rockfill or combination.	The cutoff will probably be about 20' into bedrock and a grout curtain will be essential. Grout take should be moderate.
Sec.5,T1N, R5E,HB&M	Dinsmore	Van Duzen	<u>Right Abutment</u> -- The upper portion of the right abutment is underlain by thinly interbedded, fractured sandstone and shale overlain by talus and thin soil. The lower abutment is underlain by hard, massive sandstone and conglomerate overlain by terrace materials. Chert also occurs on this abutment. <u>Channel Section</u> -- The right bank of the channel is underlain by massive sandstone. Blocks, boulders, and slide material obscure bedrock in the left channel. <u>Left Abutment</u> -- The lower left abutment bedrock is overlain by landslides, terrace and soil. Metamorphosed sediments and volcanics and unaltered sandstone and shale underlie the higher parts of the abutment.	Estimated for an earthfill dam 250' in height. <u>Right Abutment</u> -- <u>Impervious section</u>: Upper portion; 6' soil and 10' rock. Middle portion; 15' soil and 10' rock. Lower portion; 0' - 20' soil and 10' rock. Excavation will be mostly common except in the jointed hard rock in the lower portion of the abutment. <u>Channel Section</u> -- <u>The channel, approximately 80' wide is filled to a depth of about 15' with stream gravel, boulders and blocks. An additional 10' of jointed hard-rock excavation is required beneath the channel. <u>Left Abutment</u> -- <u>10' - 20' of loose</u> rock and soil should be removed plus about 10' of rock by common excavation.	A spillway location is recommended around the left abutment. The right abutment is suitable for a dam less than 180' in height. Both spillway sites are founded in sandstone and shale and would require lining.		I-Landslide debris and colluvium 1/2 to 1-1/2 mi. east of the site. P-River alluvium in the Van Duzen River channel 1 to 5 mi. upstream from the site. RR-A large block of resistant glaucophane schist located 1/2 mi. south of the site.	Moderate to high	Earthfill.	

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
SE 1/4,Sec.5, T1N, R5E, HB&M	Camp	Van Duzen	Right Abutment -- Metavolcanic rocks are present adjacent to the channel. Sandstone and shale comprise the bedrock occurring above the volcanics. The rocks are strongly jointed. Channel Section -- The channel is approximately 80' wide and is covered to a depth of about 15' with stream alluvium. Left Abutment -- The left abutment is composed of unaltered, metamorphosed sandstone and shale except near the channel where metavolcanic rocks are present. The rocks are strongly jointed.	Right Abutment -- Stripping depth is estimated to be 15' for the impervious section. Channel Section -- Stripping is estimated at 15' of alluvium plus 10' of rock beneath the impervious section. Left Abutment -- Stripping beneath the impervious section is estimated to average 10' of common excavation. Some hardrock excavation near the channel may be required to a depth of 5'.	Either abutment is suitable for a spillway. The left abutment is topographically more favorable, whereas the right abutment is in sounder rock but would require more excavation. Both locations would require lining of the spillway.		I-Landslide debris and colluvium 1/2 to 1-1/2 mi. east of the site. P-River alluvium in the Van Duzen River channel 1 - 5 mi. upstream from the site. RR-A large block of resistant glaucophane schist located 1/2 mi. south of the site.	Moderate to high	Earthfill.	1. A small fault in the right abutment may require some treatment. 2. A small tributary stream on the downstream side of the right abutment will require diversion when flowing.
NE 1/4 Sec.12, T1N,R4E,HB&M	Forks	Van Duzen	Rock types are dark, hard massive greenstone and fine grained layered sandstone. There are extensive earth flows downstream and a rock slide on the left abutment. All rock units are moderately jointed. No major faults were noted at the site but a number of minor shears were observed.	Estimated for a dam approximately 400' high. Right Abutment -- Impervious section: 5' talus and 5' weathered rock. Pervious section: 5' talus and slopewash. Channel Section -- Channel fill is 15' to 20' deep. Bedrock stripping: Impervious section: 5' of jointed rock. Pervious section: Less than 1' of loose rock. Left Abutment -- Impervious section: 10' slopewash and 5' rock. Pervious section: 10' overburden.	A saddle north of the right abutment is recommended as a spillway site. Depth to sound rock, predominantly sandstone, is approximately 25'. Beams will be required for protection every 50'.		I-Landslide debris within 1 mi. downstream of the site. P-Alluvium in the river channel about 3 mi. upstream from the site. RF & RR-Sandstone upstream and above the left abutment.	Moderate to high	Earthfill and combination earth and rockfill.	Grouting in the cutoff is required with moderate to high takes anticipated.

TABLE 23 (continued)

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
E 1/2 Sec.13, T1N,R5E, W 1/2 Sec.18,T1N, R6E, HB&M	Buck Mountain	Van Duzen	Right Abutment -- The right abutment is underlain by landslide material which averages 25' in depth. No outcrops are present but bedrock is inferred from slopewash to consist of deeply weathered Franciscan shale and sandstone. Channel Section -- The channel is over 1/4 mi. wide and is covered with alluvium to an estimated maximum depth of 50'. The alluvium is composed of unconsolidated sand and gravel derived primarily from Franciscan sandstone and related rocks. Left Abutment -- Intensely weathered and fractured Franciscan shale and sandstone underlie the abutment. A thick accumulation of slopewash occurs at the base of the abutment.	Estimated for a 200' high earthfill dam. Right Abutment -- Impervious section: Remove all landslide debris and about 5' of deeply weathered bedrock. Total: 20'-25'. Pervious section: 5' average of landslide material. Channel Section -- Impervious section: Remove all alluvium to insure cutoff. Maximum depth of trench = 50'. Average depth = 35'. Pervious section: Extensive testing necessary to determine the suitability of alluvium as foundation material. Left Abutment -- Impervious section: 25' or more of landslide and slopewash and weathered intensely fractured bedrock. Pervious section: 5' - 10' of landslide and slopewash.			I-Weathered shale and sandstone as well as colluvial deposits can be used as impervious fill and are present in sufficient quantities. P-River alluvium will be suitable. RF-No suitable source found near the site.	Moderate to high		The Buck Mountain damsite is not recommended. Wide alluvial channel and poor foundation conditions as well as presence of better sites downstream make the site undesirable.
Sec.19,T1S, R7E,RB&M	Enlarged Ruth	Mad River	Right Abutment -- Consists of hard, moderately jointed Franciscan sandstone with relatively thin shale interbeds. The rock is moderately weathered. Channel Section -- Same conditions as encountered for the present Ruth Dam. Left Abutment -- Underlain by deeply weathered intensely fractured black shale with occasional sandstone lenses. Deep cover of overburden - soil and shallow earthflow material.	Estimated for an earthfill dam 250' high. Right Abutment -- Impervious section: Remove 15' - 20' of weathered, jointed sandstone and shale. About 10' of stripping will be required for the pervious zones. Channel Section -- A deep cutoff trench will be required for a larger structure - 25' - 30'. 10' of overburden stripping under pervious sections. Left Abutment -- Impervious stripping will consist of removal of at least 30' of sheared, deeply weathered shale. Pervious zones will require about 10' of stripping.	The right abutment appears to be most favorable owing to better foundation rock. Side slopes in sandstone will be stable on a 1:1 with berms. The strata are dipping steeply to the NE -- into the side slope. Virtually the entire conveyance channel will be in cut in order to clear the toe of the dam.	The present cut and cover concrete conduit can be extended to serve the larger structure. Any additional outlet structures should be located in the right abutment.	I-Landslide debris similar to material used in the present dam are available within a 2-mi. radius. P-Extensive pervious to semipervious channel and terrace alluvium available within 7 mi. upstream in the Mad River channel. RF & RR-Limited quantities of sandstone and greenstone available within 3-mi. radius.	Moderate	Earthfill	The foundation conditions on the left abutment are considered to be critical for a 250' high structure. Extensive exploration is required for a proper evaluation of the site feasibility.

CHAPTER VIII. GREATER BERRYESSA PROJECT

This Chapter presents results of a reconnaissance study of several possible locations on Putah Creek for construction of Greater Berryessa Dam shown on Plate 1. The geology of two sites for such a dam are briefly presented in this Chapter and in Table 24. Plate 43 shows the generalized geology of the area and locations of probable sources of construction materials.

Monticello Damsite

A reconnaissance geologic investigation of Monticello damsite was made during March 1960 to locate construction materials and determine if the site is suitable for a dam approximately 600 feet high. A 304-foot-high concrete arch dam was completed at this site in 1957 by the Bureau of Reclamation. The axis of the new dam could be situated slightly upstream from, at, or slightly downstream from the existing dam.

Monticello damsite is on Putah Creek near the junction of Napa, Yolo, and Solano Counties in Section 29, T8N, R2W. An alternate Monticello site, downstream about 1 mile, will be discussed later in this report, as shown on Plate 43. The USGS Capay quadrangle shows the topography of the area at a scale of 1:62,500. Winters is the nearest sizeable town and is about 10 miles east of the damsite.

Access to the area is provided by the Winters-Rutherford County Road. This road crosses the right side of existing Monticello dam and reservoir.

Regional Geology

The general area is underlain by Cretaceous sedimentary rocks of the Chico and Shasta series (see Plate 43). These rocks consist mainly of shale, siltstone, sandstone, and minor amounts of conglomerate. They have a regional strike of about NNW and dip steeply to the east. Most of the area at the proposed site and immediately downstream is underlain by rocks of the Chico series. These rocks are predominantly shale and siltstone with lesser amounts of interbedded sandstone, except for the area underlying part of the damsite which is mainly a massive sandstone. A small part of the damsite and the area upstream are underlain by rocks of the Shasta series. The rocks of this series consist of shale and siltstone, with some interbedded sandstone occurring in small, narrow beds. In general, the sandstone beds predominate in the Chico series, and shale and siltstone predominate in the Shasta series. The general geology in the vicinity of these sites is shown on Plate 43.

No known earthquake activity has occurred in the area during recent time. According to C. F. Richter in "Seismic Regionalization", August 1958, the general area has an earthquake intensity of VII on the Modified Mercalli intensity scale. However, immediately at the site the intensity is expected to be lower.

Geology of the Site

The proposed site is in a fairly massive zone of predominantly sandstone rock. Minor amounts of shale, siltstone, and conglomerate are interbedded with the sandstone. Both up- and downstream from the site, shale rather than sandstone is the main rock type. The sandstone, shale-siltstone ratios are as follows:

Upstream from the site	20% sandstone-80% shale-siltstone
At the site	75% sandstone-25% shale-siltstone
Downstream from the site	40% sandstone-60% shale-siltstone

Sandstone at the site is hard, massive, medium to coarse-grained and thick bedded. In general, it is uniform grained, but occasionally contains cobbles and inclusions of shale. Small zones (6 inches to 12 inches) of shale and thin bedded siltstone are interbedded with the sandstone.

The shale and siltstone beds at this site are believed adequate as foundation rock for a fill or concrete gravity dam because of their confined position between massive sandstone beds. The sandstone is considered adequate to support either a concrete or a fill dam of the height being considered.

A conglomerate bed approximately 100 feet thick is exposed under the upstream part of the damsite. This conglomerate bed appears to be at the contact between the Chico series downstream and the Shasta series upstream. This congomerate bed appears weak and weathered on the surface, thus it may be unsuitable as part of the foundation for a concrete structure. Several narrower congomerate beds are also exposed at the site; however, these conglomerate beds are hard and fresh and should support either a fill or a concrete dam.

Most of the rock at the site is fresh. Weathering is expected to occur only in the first 2 or 3 feet of rock near the surface and along some of the open fractures. Occasionally weathering will be deeper along some of the shale, siltstone, and conglomerate beds than in the sandstone beds.

Two outstanding geologic structures at the site are the steep downstream dip of the bedding and the prominent jointing. Joints, which are well defined cracks in the rocks, dividing them into blocks, can be grouped into several prominent sets. One set is a general east-west trend with dips in either direction. Two other sets strike to the northwest and northeast. The northwest set of joints parallels the bedding and is the most prominent. These joints are potential avenues of leakage if not properly grouted.

No large faults were noted at or near the site. However, some minor shear zones and a small fault are exposed about 500 feet upstream from the existing dam. This small fault, which is in shale, strikes and dips approximately parallel to the bedding. Unless an arch dam is considered, the fault should not present any serious problems.

Grouting of the foundation should be accomplished easily and satisfactorily. The existing Monticello dam foundation was grouted satisfactorily in 1957. Grout take was slightly over one-half sack per foot of hole. The holes were drilled on 20-foot centers to maximum depths of 125 feet.

The abutments are relatively steep with slopes of about 1:1. Very little overburden occurs on either abutment. Vegetation consists of only a few trees and a small amount of brush.

Stripping Estimates. The stripping estimates are based on surface information and on the amount of stripping required for the existing 304-foot concrete arch dam. Stripping depths may vary considerably under different portions of the dam because of several different rock types. A massive zone of predominantly sandstone, which is described above, underlies the central part of the damsite area. Shale and siltstone occur on each side of the massive sandstone.

Abutments

Concrete Gravity	Approximately 25 feet; consisting of a 1-foot soil mantle and 24 feet of weathered and loose rock.
Earthfill	Approximately 25 feet beneath the cutoff trench and 5 feet under the remaining portion of the dam. The 5 feet will consist mainly of the soil cover and loose rock necessary for shapping.
Rockfill	Approximately 25 feet beneath the impervious section and 10 feet beneath the pervious zone. Stripping under the pervious zone will consist of loose and weathered rock, including the amount necessary for shaping.

Channel

Concrete Gravity	Approximately 30 feet; consisting of river sand and gravel and several feet of underlying weathered rock.
Earthfill	Approximately 30 feet beneath cutoff trench and 5 feet under the remaining portion of the dam.
*Rockfill	Approximately 30 feet under the impervious and 20 feet under the pervious.

*If the total rock content of the dam is less than 40 percent, the rockfill stripping depths can be decreased slightly.

Spillway

The spillway can probably be located on the right abutment or across Rocky Ridge approximately one-quarter mile south of the site. Most of the rock excavated from the ridge could be used in the rockfill portion of the dam. Cut slopes should stand at about 1/2:1. Little or no lining will be required.

Another possible spillway is located about 6 miles southwest of the site in Section 26, T7N, R3W. Elevation at this location is 900 feet, thus some excavation would be needed. Cut slopes should stand at about 1:1. Lining should not be necessary. Water from the discharge channel would flow south into Lake Curry.

Construction Materials

Suitable appearing impervious, impervious to semi-pervious, and pervious materials are available within 6 miles of the site. The closest known source of concrete aggregate is in Cache Creek at a distance of about 25 miles. (See Plate 43 for locations of potential sources of materials.)

Impervious Material. In Area 1, approximately 10,000,000+ cubic yards of suitable appearing impervious material are located 1 to 3 miles southwest of the site. The material, which is probably a clayey-silt, occurs on the small ridges and slopes along the west side of Rocky Ridge. Common excavation should be practical to a depth of 12 to 15 feet. The clayey-silt is a residual material of weathered shale and siltstone. It has an estimated cohesion of 1/2 Ton/SF, a phi angle of 20°, and an in-place density of 115 pounds per cubic foot. Approximate elevation of this borrow area is about 500 feet. The area is covered with a moderate amount of brush and a few scattered trees.

In Area 2, the material is probably the most suitable for impervious fill. It is located 3 to 6 miles east of the site and consists of sandy-silt, silty-clay, and some medium to coarse sand and gravel. This material has an estimated cohension of 1 Ton/SF, a phi angle of 15°, and an in-place density of 120 pounds per cubic foot. An estimated 20,000,000+ cubic yards are available with common excavation methods. The material is considered to be a younger alluvial deposit. Approximate elevation is 200 feet. Most of the area is covered with various types of orchard trees.

Impervious to Semi-Pervious Material. In Area 3, approximately 30,000,000+ cubic yards of Tehama clay, silt, sand, and gravel are available. The material is about half sand and gravel and half silt and clay. There is some question regarding the suitability of this material for use as impervious material; therefore, until permeability tests are made, it is recommended as semi-pervious. It should have a relatively high shear strength. Samples of similar material (Tehama formation) from various other locations have an average cohension of 1/4 Ton/SF, a phi angle of 30°, and an in-place density of 110 pounds per cubic foot. Common excavation should be practical to depths of 25 to 30 feet in places. Approximate elevation of the area, which is about 4 miles east of the site, is 250 feet. There is very little vegetation.

Rockfill or Riprap. Hard fresh sandstone is available near the site in areas 4, 5, and 6. This rock is massive to moderately jointed and should break into blocks 3 to 4 feet in size. The sandstone contains some interbedded shale and siltstone. However, by careful selection of the exact quarry location, only a few narrow zones of shale-siltstone need be encountered. The sandstone, shale-siltstone ratio would then be about 90:10. The rock is expected to have a placed densith of about 110 pounds per cubic foot and a phi angle of about 40°. Less than 25 percent of the rock is expected to break into sizes of 6 inches or less, while blasting to obtain average sizes of 3 or 4 feet.

The rock in area 4, which includes the right abutment of the site and the ridge southward for about 2 miles, is considered to be the best quarry area. All quarry operations can be at or above damsite elevation. Approximate quantities of rock available are as follows:

Area 4	20,000,000+ cubic yards
Area 5	5,000,000+ cubic yards
Area 6	30,000,000+ cubic yards

Concrete Aggregate. The closest known source of aggregate is located northwest of the site at Cache Creek. This area, which is at a haul distance of about 25 miles, supplied the -3-inch material for the existing dam. The +3-inch material was obtained from the American River, east of Sacramento, at a haul distance of about 50 miles.

Reservoir

The reservoir area is underlain chiefly by shale and siltstone with minor amounts of interbedded sandstone and alluvial valley fill. It should be a tight reservoir. About half of the area is range land with a fairly light cover of brush and trees. The remaining half is farmed valley land. Several small settlements and numerous homes would be inundated. Most of these features are in Pope Valley and Capallo Valley. The most important features to be either inundated or incorporated into the present proposed dam project are the existing 304-foot Monticello Dam and Reservoir.

Alternate Monticello Damsite

An alternate Monticello damsite (shown as "Enlarged Monticello Damsite", Plate 43) was briefly investigated. It is located in Section 28, T8N, R2W, and is downstream approximately 1 mile from the existing, above-described Monticello damsite.

The site is underlain by Chico shales, siltstone, and lesser amounts of thin bedded sandstone. The bedding strikes about NNW and dips about 70° downstream. The rock types are similar to those at the upstream site, but shale and siltstone beds are predominant rather than sandstone beds. The sandstone, shale-siltstone ratio is about 40 to 60 percent. The shale and siltstone, which are more rapidly affected by weathering than the sandstone, have not been appreciably protected between massive sandstone as has been the case at the upstream site. As a result, the slopes are flatter and the underlying rock weathered to greater depths. No large faults or shear zones were noted. However, minor shears are expected.

The abutments have an average slope of about 1-1/2:1 and a light covering of brush and trees.

The site appears suitable for a fill dam but is not recommended for a concrete dam. This is because of a large amount of relatively weak shale and siltstone.

Stripping will be uneven because of interbedded shale, siltstone, and sandstone. The estimates are given normal to the surface and based only on surface information.

Abutments

Earthfill	Approximately 35 feet beneath the impervious or cutoff trench; consisting of a 2- or 3-foot soil cover, and weathered and loose rock. Three or four feet of stripping should be sufficient under the remaining portion of the dam.
Rockfill	Approximately 35 feet under the impervious section and 20 feet for the pervious. The 20 feet of pervious will consist of soil and highly weathered material.

Channel

Earthfill	Approximately 35 feet beneath the cutoff trench and 5 feet under the remaining portion of the dam. The removed material will be chiefly river sand and gravel.
Rockfill	Approximately 35 feet under the impervious and 25 feet under the pervious.

General Comments

1. Monticello damsite appears suitable for a high fill or concrete gravity dam. The axis should be situated slightly upstream from the existing dam if possible, to avoid a weak zone of shale and siltstone which occurs approximately 400 feet downstream from the dam. If this location is not practical because of the present reservoir, a fill dam could probably be constructed satisfactorily with the axis at or slightly downstream from the dam.

2. A high concrete arch dam is not recommended for Monticello damsite because of weak shale and siltstone which would be an unavoidable part of the foundation.

3. Construction materials, exclusive of concrete aggregate, are available within 6 miles of the site. Aggregate can probably be obtained approximately 25 miles northwest of the site in Cache Creek or in the American River east of Sacramento.

4. The reservoir, which is underlain by shale and siltstone, should be tight.

5. The alternate Monticello damsite does not appear as suitable for a dam as the upstream Monticello site; however, a fill dam could probably be constructed satisfactorily. A concrete dam is not recommended at this location.

6. This report should be used only for preliminary cost estimates. If further consideration is given either of the damsites the following general items should be studied.

a. Monticello damsite
   (1) Additional study of available information obtained by the Bureau of Reclamation during construction of the existing dam.
   (2) Testing of the abutments above an elevation of 300 feet above streambed and downstream from the existing dam.
   (3) Testing of construction materials.

b. Alternate Monticello damsite
   (1) Detailed geological mapping of the abutments.
   (2) Testing of the abutments as deemed necessary from the mapping.

TABLE 24

GEOLOGIC CHARACTERISTICS OF DAMSITES

Greater Berryessa Project

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
T7-8N,R1W, MDB&M	Monticello Afterbay	Putah Creek	Right Abutment -- The right abutment is underlain by interbedded tuff, tuff breccia and gravels of the Tehama formation. Some gravel beds are cemented. The dip is slightly downstream. Channel Section -- The wide channel area is underlain by alluvium to a probable maximum depth of 50'. Tehama formation tuff beds and sediments are inferred to underlie the alluvium. Left Abutment -- The left abutment is underlain by interbedded silty sandstone and gravels. The tuff member of the Tehama formation is inferred to lie at depth beneath the abutment.	Estimated for an earthfill dam 80' high. Right Abutment -- Impervious section: Strip up to 70' of tuffaceous sediments and pervious gravels. Pervious section: Strip 5' - 10' of weathered rock and soil. Channel Section -- Impervious section: Strip up to 50' of alluvium plus 20' of Tehama sandy siltstone and gravels. Pervious section: 5' - 10' of soil and alluvium. Left Abutment -- Impervious section: Strip 5' of soil plus 20' of weathered Tehama gravels and silty sandstone. Pervious section: Strip 5' - 10' of weathered rock and soil.	An around end type spillway may be constructed on the right abutment. It will be in Tehama tuffs and gravels and will require concrete lining to maximum water flow level. Spoils will probably be unusable.		I-Valley alluvium is available in sufficient quantity adjacent to Putah Creek within 3 mi. of the site. P-Tehama sand, clay and gravels are available in sufficient quantities 2 - 3 mi. northwest of the site. RF & RR-Sandstone may be quarried selectively from ridges 3 - 5 mi. west of the site.	Moderate	Low earthfill dam, if measures are taken to overcome special problems.	The interbedded tuffs and gravels at the site are subject to seepage, uplift and consolidation. A row of relief wells is recommended downstream to relieve uplift pressures.

CHAPTER IX. LOWER EEL RIVER PROJECTS

The engineering geology of the two principal project features are discussed in detail in this Chapter. These projects include Sequoia and Bell Springs Dams. New water developed by these projects would be pumped into Dos Rios Reservoir and from there through facilities constructed for the Upper Eel River Development. Plates 44 to 47 are a series of geologic maps, cross sections, and construction material locations maps for each of these projects.

Geologic data for two other damsites, which have been studied in much less detail, are presented in Table 27. These sites are Island Mountain and Woodman sites.

Sequoia Damsite

Sequoia damsite is located on the Eel River about 3 miles upstream from the settlement of McCann, a station on the Northwestern Pacific Railroad. The axis is nearly coincident with the section line between Section 1, T2S, R3E, and Section 6, T2S, R4E, HB&M.

Topography of the general area is shown on the 15-minute, 1951 edition of the Weott Quadrangle, published by the USGS. This map has a scale of 1 to 62,500 and has a contour interval of 50 feet. For more detailed topography of the damsite, a map at a scale of 1 inch to 200 feet with a 20-foot contour interval was prepared by the Department of Water Resources.

Access to the site is by a dirt county road from Highway 101 at Dyerville to McCann, across a low-level bridge to the right side of the river. From there the road continues to the site and crosses the axis on the right abutment. A county road leads to Whitlow Post Office on the left side of the river about a mile downstream from the site. From there the left abutment can be reached by walking along the railroad right-of-way.

Purpose and Scope

To evaluate foundation conditions of the site, seven diamond drill core holes were drilled, and a geologic map of the area surrounding the site was prepared during the fall of 1958. Possible sources of construction materials were sampled and the areas delineated on a topographic map.

Other work included standard laboratory tests on soil and aggregate samples and strength tests on core samples.

Description of Project

A rockfill and gravel fill dam over 600 feet high has been considered for Sequoia damsite. However, the possibility of the site being suitable for a concrete structure was also considered during the exploration, and for that reason this report will evaluate foundation conditions for both types of dams.

The proposed cut for the spillway would be through the right abutment, and with the spillway crest at an elevation of 695 feet the reservoir would provide a storage capacity of about 5 million acre-feet. A diversion tunnel about 4,000 feet long is proposed beneath the left abutment.

Geology of the Site

Topography is very rugged in the immediate area of the damsite where steep slopes are formed by resistant sandstone. Downstream from the axis, slopes flatten considerably due to the presence of a weaker underlying shale and interbedded shale and sandstone.

The two geologic formations exposed at the site are the Franciscan of Jura-Cretaceous age and the Yager of Cretaceous age. The Yager formation has been divided locally into three units: Yager shale, Yager sandstone, and Yager conglomerate.

The Franciscan rocks are exposed about 2,000 feet upstream from the axis where they are in fault contact with Yager conglomerate. Rock types found in this group consist of graywacke sandstone (both fresh and hydrothermally altered), black shale, and minor amounts of chert. These have been intruded locally by small bodies of serpentine. The structure proposed for this study would be largely founded on the Yager formation rock. Geology of the site is shown on Plate 44, "Geologic Map and Sections, Sequoia Damsite".

The Yager formation is much less structurally deformed than the Franciscan in that bedding planes are easily descernible, and contacts between members are sharp and can be easily followed.

Yager Shale. This unit is exposed about 200 feet downstream from the axis and extends in that direction for a considerable distance.

It consists of black thinly bedded shale with minor amounts of interbedded thin sandstone layers. Generally these rocks are relatively weak and do not support very steep slopes. Slight shearing is not uncommon, but the beds are not contorted and frequently maintain a rather consistent attitude.

The interbedded sandstone is black, well-cemented, fine to medium-grained, and occurs most frequently as beds averaging 6 inches in thickness. Both the shale and interbedded sandstone appear to be unweathered and sound at relatively shallow depths.

Yager Sandstone. The proposed axis lies almost entirely within a thickly bedded, hard, quartz-rich sandstone which as a unit measures 680 feet thick in a direction normal to the bedding planes. It is highly resistant to erosion and forms steep canyon walls. The sandstone is well-cemented, medium- to coarse-grained, and has a light gray color when fresh, weathering to light brown.

The contact with the underlying shale is conformable, sharp, and free from faulting or shearing; the contact with the overlying conglomerate is indistinct and somewhat gradational. The sandstone will serve as an excellent foundation and as much of any concrete structure as possible should be founded on it.

Yager Conglomerate. This unit overlies the sandstone and is about 800 feet thick, measured normal to the bedding. The conglomerate is cut off by a fault, about 2,000 feet upstream from the axis. This fault juxtaposes the Yager with the Franciscan formation. The Yager conglomerate is massive, and poorly sorted with rock fragments ranging in size from pebbles to boulders and cemented by a sandstone matrix. Interbedded with the conglomerate are thin sandstone beds or lenses. Cementation between the boulders and cobbles and the matrix is so poor that the fragments weather out easily. Due to this fact, the conglomerate was difficult to drill because the fragments became loosened from the matrix rather than being drilled through. This contributed to frequent blocking of the core barrel.

Exploration of Foundation Rock

A total of seven diamond drill core holes were drilled -- one on the right abutment, a spillway hole on the ridge above the right abutment, and three holes on the left abutment. Also, two holes were drilled in the channel area. Drilling difficulties were experienced with the left channel hole, LC-1, at a depth of about 190 feet, resulting in redrilling at a less steep angle. The redrilled hole was designated LC-1A. Locations of the drill holes are shown on Plate 44 and data concerning the drill holes and water tests are summarized in Table 25.

Except for hole S-1 at the spillway, the drill holes were confined to the Yager sandstone. Hole S-1 penetrated about 100 feet of Yager conglomerate before encountering sandstone (see geologic sections, Plate 44). Holes ranged in depth from about 89 feet to 252 feet with the total aggregate footage being about 1,100 feet.

Foundation Conditions

Right Abutment. The right abutment rises steeply from the channel at a slope of nearly 100 percent to an elevation of about 600 feet. From there, the slope decreases gradually to about 45 percent near the top of the ridge. Rock exposures in the axis area are excellent and consist of resistant sandstone. The right abutment supports a moderate amount of brush and timber and in a few places some grass sod has developed.

Soil and loose rock cover is relatively thin on the portion of the abutment underlain by sandstone. Drill hole RA-1 encountered about 15 feet of such material and the average over the entire abutment should be about 10 feet. The shale downstream from the axis is much more susceptible to slumping and weathering and has developed a deeper cover of soil, an average of about 12 feet.

Sandstone encountered in drill hole RA-1 is excellent foundation rock. Core recovery, exclusive of overburden, was 99 percent, and except near fractures, the rock is fresh and hard. A zone of open fractures showing strong weathering extends to a depth of about 25 feet. Below this zone, except for a few occasional joints, the weathering is slight and fractures are relatively fresh. Water losses during pressure testing were generally high and appeared to be confined to intensely jointed zones. The sandstone can be effectively grouted, but the take will be high as indicated by the water pressure tests.

Four core samples were tested to determine unconfined compressive strength. Values ranged from 4,600 psi to 9,040 psi, indicating that the rock, where not broken or sheared, possesses considerable strength.

About 400 feet downstream from the axis on the lower portion of the abutment the Yager shales are exposed. No subsurface exploration was made of this unit because it was contemplated that the sandstone member should provide most of the foundation for a concrete structure and that the impervious section of a fill dam probably also should be located on the sandstone. The shale, together with its interbedded sandstone layers, is considerably weaker than the Yager sandstone but can certainly serve as an adequate foundation for the pervious section of a rockfill dam. In incised gullies on the abutment where the badly weathered shale and overburden have been removed, the shales appear relatively tight and only infrequently sheared. The shale is sufficiently indurated to preclude foundation settlement due to consolidation.

The contact separating the Yager sandstone and Yager conglomerate is exposed on the lower portion of the abutment about 450 feet upstream from the axis and can be followed up slope where it intersects the axis at an elevation of about 740 feet. Drill hole S-1 explored this contact, and drilled through about 104 feet of conglomerate before encountering sound Yager sandstone. The contact was found to be gradational over a stratigraphic interval of about 15 feet. No faulting was present between the two units.

Core recovery in the conglomerate was low owing to frequent blocking of the barrel. The rock is moderately fractured and occasionally sheared. No foundation settlement problem will be encountered with the conglomerate.

If the impervious section of a rockfill dam is to be located within the sandstone unit, overburden consisting of organic material and residual soil derived from the underlying bedrock should be removed. This zone is about 10 feet thick. In addition to this, about 10 feet of bedrock should be excavated which is moderately fractured and weathered and through which leakage may occur. Removal of about 10 feet of overburden will be required for the remaining foundation area beneath the pervious section.

Stripping to a depth of about 30 feet, with the upper 10 feet consisting of overburden, will be required for a concrete structure. The lower 20-foot portion consists of moderately jointed sandstone. If part of the dam is to rest on the Yager shale, stripping will consist of about 12 feet of overburden and 30 feet of moderately to slightly weathered shale.

Channel Section. At the axis the channel is fairly wide, averaging about 250 feet. Outcrops are sparce, being covered by talus and channel alluvium.

A rather large amount of channel fill was encountered in both RC-1 and LC-1 before reaching sandstone bedrock. Both of these holes encountered stream sands and gravels and boulders of sandstone and conglomerate up to about 2 feet in diameter. The depth of the channel fill was 93 feet in RC-1 and 75 feet in LC-1. In vertical thickness along the center portion of the channel, depth to sandstone bedrock would be about 70 feet.

Both channel holes were drilled into the Yager sandstone and excellent core recovery was obtained; 95 percent for RC-1 and 96 percent for LC-1 and 1A. The rock consisted of hard, unweathered, fine to coarse-grained sandstone. Rock in RC-1 was moderately fractured, and although the fractures were practically free of any weathering or iron stains, they were fairly open and contained thin clay coatings and occasional gouge zones.

Hole LC-1 encountered rock which was also only moderately fractured. Fractures are more weathered than those in RC-1 and iron oxide stains are common down to about 135 feet. Fractures appear to be quite open at least from 74 feet to 178 feet. In this interval no pressure could be maintained during water testing. Water tests in the interval from 179 feet to 250 feet were made at pressures up to 180 psi with a loss of 24 gpm.

No continuous fault is present in the channel. In view of the water test data and amount of fracturing, the grout take is expected to be moderate.

Stripping for the foundation of a concrete dam will require the removal of up to 70 feet of channel fill and 10 feet of moderately jointed bedrock. For a rockfill or earthfill dam beneath the impervious section, only channel fill and 5 feet of weathered rock will need to be removed. The pervious section of such a dam may rest upon the stream sands and gravels.

Left Abutment. Slopes on this abutment in the axis area are quite steep and average slightly more than 100 percent. In places the resistant Yager sandstone has formed nearly vertical cliffs. Except in the lower portion of the abutment where the Yager sandstone is very well exposed, the left abutment has a much heavier growth of trees and brush than the right. Thus, the rock higher on the abutment is poorly exposed. Overburden consisting of soil cover and talus is also thicker on the left abutment than on the right.

The same rock units and types are exposed on the left abutment as on the right. Since the Yager formation dips slightly into the right abutment, the contacts between the different members are exposed somewhat further upstream in relation to the axis than they are on the right (see Plate 44). Otherwise the rock types of the different members, their physical properties, and their foundation problems are similar on both sides.

The sandstone unit on the left abutment is more highly jointed and fractured, and has developed three prominent sets of joints. The most prominent one is parallel to the bedding planes. The other two are both perpendicular to the bedding - one dipping downstream about 40°, the other nearly vertical. This latter set contributes to the formation of vertical cliffs and may be the major cause of the rock falls for which the railroad has constructed a concrete retaining wall just downstream from the tunnel.

The joints are quite open at the surface and appear to be only partially closed at depth. The majority of the fractures noted from the drill core are open, occasionally to depths of up to 100 feet. Some open fractures contain clay or gouge and are discolored to light brown on the surface.

Foundation exploration of the left abutment consisted of three drill holes, two of which (LA-1 and LA-3) yielded excellent core recovery. In the other hole, LA-2, the core recovery was very poor and the rock was rather badly weathered and broken. As was later determined, the hole was drilled nearly parallel to the plane of bedding and probably followed one of the weathered zones along the bedding plane fractures. Thus, a representative cross section of the rock was not obtained with this hole; however, it did show that weathered rock associated with these zones exists to depths as great as 100 feet. High water losses were associated with poor rock in LA-2.

Because of the poor recovery in hole LA-2, an additional hole (LA-3) was drilled more nearly normal to the bedding planes. The rock in this hole and in LA-1 cored well. Core recovery in each hole was 96 percent since no pressure could be developed.

The major problem with the sandstone is the apparent openness of fractures and joints up to relatively great depths, as evidenced by weathering along the fractures, high water tables, and the lack of pressure during holding tests. Thus, it is believed that the grout take will be rather high, although grouting will probably be effective in open fractures.

The sandstone is adequate to support the proposed structure. Unconfined compressive tests of representative core from the left abutment holes gave values from 6,500 psi to 22,450 psi.

Stripping estimates are given normal to the ground surface. Both a rockfill and a concrete structure are considered for purposes of foundation evaluation and stripping estimates.

For a rockfill dam with the impervious section located within the sandstone unit, overburden, consisting of talus and residual soil derived from the underlying bedrock, should be removed. This zone averages about 12 feet in thickness. In addition to this, 5 feet of bedrock should be excavated which is moderately fractured and weathered. Removal of about 5 feet of overburden will be required for the remaining foundation area beneath the pervious section.

For a concrete dam resting on the Yager sandstone, the overburden averaging 12 feet thick should be removed beneath the entire foundation area. In addition to this, about 25 feet of moderately jointed and weathered sandstone should be excavated. If part of the dam is to rest on the Yager shale, about 30 feet of the moderately to slightly weathered shale should be removed in addition to the overlying 12 feet of overburden.

Spillway

A completely lined ogee weir and chute spillway designed for a maximum flow of 488,000 cfs is proposed through the ridge forming the right abutment (see Plate 44). A spillway on this abutment is much more favorable topographically than on the left, as a relatively broad ridge would have to be cut through on the left side, resulting in a higher volume of excavation.

The weir section will rest on both the Yager sandstone and the Yager conglomerate, which will serve as satisfactory foundation material. Because of the dip of the rock, a greater part of the excavation (about 60 percent) for the weir will be in conglomerate. The remaining 40 percent will consist of thickly bedded, hard sandstone, which will require heavy blasting. Drill hole S-1, located above the proposed cut, encountered about 100 feet of broken conglomerate before reaching fresh sandstone.

Due to the steepness of the right abutment, a large cut will be required for the chute section. The upper one-third of the section will be through hard, resistant sandstone and the lower two-thirds through the weaker Yager shales. Below a 10- to 15-foot thickness of overburden, rock suitable for the foundation should be exposed. Blasting will be required in the sandstone; common excavation will be possible in the shale. Cut slopes should be about 1 to 1 in the shale and 3/4 to 1 in the sandstone. The spillway chute should be concrete lined. Loose rock will have to be removed from the abutment above the cut slopes to prevent talus and rock slides. A stilling basin will be located at the base of the chute entirely in Yager shale.

An overflow spillway will be suitable if a concrete gravity structure is constructed and will eliminate the large amount of excavation necessary for the weir through the right abutment. For either an overpour spillway or a weir and chute, the discharge area will be underlain by shale. Although the shale is competent for a part of the foundation of a concrete gravity dam, it would be rather easily eroded under strong hydraulic action, and will require a concrete lined stilling basin.

Diversion Tunnel

A diversion tunnel, as shown on Plate 44, is proposed through the left abutment. Diversion through the left abutment is more favorable than through the right abutment because of the slight bend in the river around the left side. The tunnel at this location would have a maximum cover of over 600 feet.

Although no faults or shear zones were observed in the railroad cuts on the left abutment, there is a possibility that the fault exposed on the right abutment extends beneath the channel into the left abutment. Judging by the strike of this fault, it would intersect the tunnel alignment in the conglomerate, about 75 feet downstream from the conglomerate-sandstone contact. The fault is vertical so that tunneling would be through a crushed zone only 15 feet wide as measured along the tunnel alignment.

The greater part of the tunnel will intersect the bedding planes of the rock at a favorable angle, about 65 degrees in a horizontal direction and 60 degrees in a vertical direction.

Listed below are the estimated physical properties of the rock at tunnel grade and their approximate average rock load factors as defined in Department of Water Resources Bulletin No. 78, Appendix C, "Procedures for Estimating Cost of Tunnel Construction".

1. Massive conglomerate -- 25 percent of tunnel length. The rock is very blocky and seamy with an average rock load factor of 0.725 (B+Ht). High overbreak is anticipated in this zone.

2. Thickly bedded sandstone -- about 40 percent of tunnel length. Tunneling conditions will be stratified to moderately fractured rock. Rock load factors to be used in cost estimate are 0.5 B.

3. Shale with interbedded thinly bedded sandstone - 35 percent of total length. Rock loads will average at 0.35 (B+Ht) and tunneling conditions can be described as moderately blocky and seamy.

Reservoir Area

The reservoir area lies entirely within rocks of the Franciscan group consisting principally of sandstone and black shale, similar to rock exposed just upstream from the site. There rocks are sufficiently impervious to prevent any reservoir leakage. Silting is expected to be moderate.

The possibility of land sliding into the proposed Sequoia Reservoir presents a very serious hazard -- overtopping of the embankment by landslide induced waves. The entire reservoir lies in an area of unstable slopes and several large scale active slides will be inundated. Virtually all large slides are of the earthflow type and slope movement is generally confined to shallow zones in the weathered saturated bedrock. (See Attachment B for a more complete discussion of landslides.)

Construction Materials

During September and October 1957 a preliminary survey of construction materials near Sequoia damsite was made. This consisted of delineating the thicknesses and areal extent of possible sources of pervious and impervious fill, concrete aggregate, and riprap. Representative sack samples obtained of some of the deposits were tested at the soils and concrete laboratories.

Ample quantities of apparently suitable pervious material for a fill dam or aggregate for a concrete structure are available within a haul distance of 8 miles. Impervious material is available within a haul distance of 4 miles. Areal extent and distribution of these deposits is shown on Plate 45.

Impervious Material. Two principal types of deposits were investigated -- river terrace deposits and residual soil in the upland areas. None of these materials have been adequately tested, but on the basis of preliminary tests the material can be utilized.

The river terraces are exposed from about 8 to 10 feet above the river channel and occur between the settlements of South Fork and McCann. The material is rather heterogeneous, varying both laterally and vertically, but for the most part consists of fine-grained sand with interbeds of sandy silt and sandy clay. With an average depth of 15 feet, after removal of the upper 2 feet, nearly 12 million cubic yards were present in areas 2, 3, 5, and 6. These are delineated on Plate 45.

The second type of material sampled for impervious fill consists of residual soil deposits and old slide material and is shown on Plate 45 as areas 17, 18, 19, 33, 34, and 35.

Area 33, (shown as two areas), about 3/4 mile north of the site, consists of slide material of sandy silt and sandy clay derived from the graywacke and serpentine bedrock. Approximately 2 feet of organic material must be stripped. About 335,000 cubic yards of usable material are present. Surface seeps and marshy areas indicate a high water table.

Area 35 is a sloping deposit located about 1 mile east of the axis and is composed of sandy silt and weathered rock fragments. It is derived mainly from graywacke and should be stripped of organic matter to a depth of 2 feet. The usable material is estimated to be about 5 feet thick and to consist of about 750,000 cubic yards.

An extensive residual soil deposit, varying in distance from 3 to 5 miles from the site, is located on Mail Ridge. This includes areas 17, 18, 19, and 34, the latter three having been delineated from the main mass as representing areas of greater thickness. A deep root zone will necessitate stripping of about 2 or 3 feet of overburden. Topography varies from moderately steep to flat. The material sampled at area 17 was tested for permeability and at a compacted maximum density the material was practically impervious. It can be considered as a source of suitable material yielding about 4 million cubic yards from areas 17 and 19 alone.

Pervious Fill or Concrete Aggregate. Within the channel section of the Eel River between the confluence of the South Fork, a distance of 8 miles downstream from the site, and the settlement of Smith, 1 mile upstream from the site, lies an extensive deposit of sand and gravel. It is conservatively estimated to be about 30 feet thick, and if so about 39 million cubic yards are located in this area. Excellent accessibility is provided by a road which parallels the river from Dyerville to McCann, where it crosses the river and continues to the site.

This material has not been sampled to test its suitability for pervious fill. However, it should serve very satisfactorily and ample quantities are present. No excavation problems should be encountered.

A number of samples were collected and tested for suitability as concrete aggregate. On the basis of these tests the gravels are considered suitable for concrete aggregate when used with low alkali cement.

Rockfill. Rockfill material for the proposed structure will be available in part from the spillway excavation and the remainder will be quarried from the Yager sandstone. The precise locations of potential quarry sites have not been delineated at this time; however, for preliminary cost estimates it was assumed that an adequate volume of rock can be obtained within a 2-mile radius.

Riprap. About 3/4 mile northeast of the site is a mass of hydrothermally altered and silicified arkosic sandstone which should yield an estimated 375,000 cubic yards of good quality riprap. This area is designated as area 40 on Plate 45. The rock is sound, unweathered, well-indurated, and moderately jointed. Talus below the massive outcrop displays blocks ranging in size from 1 to 3 feet in diameter. If blasting can produce this size, the sandstone should produce satisfactory riprap. Additional material may be salvaged from the spillway excavation in the Yager sandstone.

Conclusions

1. Sequoia damsite is entirely suitable for the proposed rockfill dam and ample construction materials are present within a radius of 8 miles. If possible, the impervious section should be located within the Yager sandstone unit. Grout take will be moderate to high in the sandstone.

2. A spillway located through the right abutment is more favorable topographically than through the left, although rather large cuts will be necessary, particularly for the spillway chute. The entire spillway terminating in a stilling basin should be concrete lined.

3. The site should also be considered suitable for a concrete gravity structure of equal height. Ample material suitable for concrete aggregate exists close to the site.

4. Since the sandstone is the most competent rock of the three members exposed at the site, a concrete structure should rest on the sandstone as much as possible. The remainder should be located on the shale. The conglomerate, being somewhat unpredictable as to strength and degree of weathering, should be avoided.

Recommendations

If this site is further considered, the following additional exploration is recommended and should be included in any feasibility level investigation.

1. Foundation exploration.
   a. Right abutment. At least one additional hole should be drilled at an elevation of about 600 feet in the sandstone unit. One or more diamond drill holes should be drilled in the shale unit. An exploratory drift into the abutment should be excavated to observe the sandstone at depth.
   b. Channel section. Further exploration is required to determine thickness of channel fill and condition of the bedrock.
   c. Left abutment. Additional drill holes are required to explore the rock upstream and downstream from the drift into the sandstone on this abutment.

2. Landslide investigation. A detailed landslide study is recommended to determine the probability of large scale slide movement into the reservoir and to provide design criteria for a safe embankment.

3. Construction materials. All sources of construction materials should be further explored and tested. The impervious borrow areas should be explored by auger holes and backhoe trenches. The quarry areas should be drilled and test blasting conducted to determine breakage characteristics of the rock.

TABLE 25

SUMMARY OF EXPLORATION
OF SEQUOIA DAMSITE

Foundation drill hole No.	Date started / Date completed	Location	Elevation (ft.)	Inclination	Total depth (ft.)	Typical water losses	Rocks encountered and geological properties	Percent core recovery (excl. of overburden)
RA-1	9-4-57 / 9-6-57	Right abutment, on dam axis		45° N23E	100.0	Interval tested: 14.9' Loss: 0.38 gpm/ft. At 130 lbs./in.^{2}	15 feet of residual soil overlies gray, medium-coarse grained sandstone with fractures open to 100 feet in depth.	99
RC-1	8-13-57 / 8-29-57	Right channel, on dam axis		65° S8°W	252.3	Interval tested: 81.6' Loss: 0.24 gpm/ft. At 150-160 lbs./in.^{2}	93 feet of loosely consolidated river alluvium overlies fractured, well indurated, fine- to coarse-grained gray sandstone.	95
LC-1 LC-1A	8-16-57 / 9-13-57	Left bank, 100' west of dam axis	160	55° N10E 53° N11E	250.3	Interval tested: 7.16' Loss: 0.30 gpm/ft. At 150 lbs./in.^{2}	75 feet of river alluvium overlies well indurated, fractured, medium-grained sandstone.	97
LA-1	9-20-57 / 9-25-57	Left abutment, on axis, 150' above retaining wall near tunnel		50° S27W	100.5	Interval tested: 62' Loss: 0.36 gpm/ft. At atmospheric pressure.	Hard, coarse-grained sandstone with numerous fractures. Weathering is intense along fractures.	94
LA-2	10-11-57 / 10-16-57	Left abutment, on axis, atop bluff above railroad tunnel		60° S81E	111.0	Interval tested: 45' Loss: 0.94 gpm/ft.	Gray, coarse-grained fractured sandstone becomes broken and crushed with depth below about 25'.	45

TABLE 25
(Continued)

Foundation drill hole No.	Date started / Date completed	Location	Elevation (ft.)	Inclination	Total depth (ft.)	Typical water losses	Rocks encountered and geological properties	Percent core recovery (excl. of overburden)
LA-3	10-19-57 / 10-21-57	Left abutment, 250' upstream from LA-2		57° S17E	89	Interval tested: 26.5' Loss: 0.77 gpm/ft. At atmospheric pressure.	Medium to coarse ground moderately fractured, well cemented sandstone.	93
S-1	9-19-57 / 10-5-57	Spillway, on ridgecrest, near axis of dam	959.8	Vertical	150.6	Interval tested: 54.5' Loss: 0.55 gpm/ft. At 55 lbs./in.^{2}	13.5 feet of soil overburden overlies poorly indurated and fractured conglomerate to 102' in depth. Sound, fractured sandstone underlies the conglomerate.	80

Bell Springs Damsite

Bell Springs damsite is located on the Eel River, Mendocino County, about 5 miles upstream from the junction of the river with its North Fork. The Northwestern Pacific Railroad traverses the lower part of the abutment. The railroad settlement of Bell Springs Station is located about 1.5 miles downstream from the site. The site is located in Section 30, T24N, R14W, MDB&M. General topography is shown on the USGS Spyrock quadrangle at a scale of 1:62,500. Detailed topography and geology of the site is shown on Plate 46, "Geologic Map and Section, Bell Springs Damsite".

The exploration program at this site was conducted from June 7 to October 1, 1957, and consisted of eight diamond drill core holes. In addition, geologic mapping of the site and limited construction materials work was done in the area. No exploration of pumping plant foundation conditions was undertaken.

Description of Project

Bell Springs Reservoir would be formed by construction of a 490-foot-high fill dam and would have a gross storage capacity of 1,350,000 acre-feet. A spillway is proposed across the right abutment and a diversion tunnel is planned through the right abutment.

The 400,000 acre-feet of yield developed plus the yield pumped up from Sequoia Reservoir would be pumped into Dos Rios Reservoir on the Middle Fork of the Eel River.

Geology of the Site

The site is underlain by steeply dipping, tightly folded beds of conglomerate, graywacke, sandstone, lenticular and continuous slaty shale beds, and units which were originally shale interbedded with thin sandstone layers. This assemblage of Franciscan rock units intersects the axis at an angle of about 35 degrees. Shearing, probably occurring primarily during the tight folding, has produced gouge zones of clayey material. Most of these shear zones contain fragments of graywacke and shale (see Plate 46).

Folding. At least two easily discernible scales of folding are seen at the site. The most apparent are the relatively large scale overturned folds of the type seen downstream from the site (right abutment) and on the north side of Blue Rock Creek about 1,000 feet upstream from its confluence with the Eel River. (The first of these is a syncline and the latter an anticline.) Both of these structures are overturned toward the southwest and plunge at about 45 degrees. It should be noted though, that the syncline appears to plunge to the south while the anticline apparently plunges northerly. No other folds of this scale were observed during the mapping; however, further detailed work may reveal additional structure. Drag folding accompanying the above major folds was observed at several localities. Some of this small scale folding observed may be due to intraformational shearing rather than drag folding.

The major folds discussed above may possibly be large drag folds resulting from folding of a larger scale than mappable at the site. The interpretations based on the drilling and mapping will, however, not be significantly affected if such is the case. Discontinuity of outcrops and the high percentage of surface covered by slopewash combined with relatively complex structure and faulting must necessarily result in a map with a high degree of interpretation.

The major zones of shearing composed of crushed and clayey material encountered in the drill holes may be associated with the folding in the area.

Faults. It should be noted that both mapped major folds show significant associated faulting. Both folds are broken by faulting and the easterly limbs of the folds have been thrust westward. Many minor faults and offsets - some recemented by calcite - were observed. The relative magnitude of these features was not determined, and no fault pattern has been developed. It should be noted that the massive shale members are often entirely surrounded by "faults". This phenomena is probably due to intraformational shearing during folding.

Description of the Rock Units

The rock units consist of lenses and narrow discontinuous zones with rapid facies changes. This type of sedimentary sequence in combination with tight overturned plunging folds accompanied by faulting and shearing produces a complicated structural picture. Interpretation is made even more difficult by the covering of landslides and colluvium in the area. An attempt was made, however, to subdivide the damsite area into geologic units based on relative abundance of rock units.

Massive Sandstone Interbedded with Minor Shale. The graywacke and gray sandstone beds constitute the most prominent resistant rock unit at the site. Where observed in outcrop, these clastic beds are well cemented by calcareous material; however, core drilling revealed zones of gray sandstones which were either weakly cemented or in which the calcareous cementing agent had been removed by ground water. These weaker sandstones could be broken easily but are nevertheless much stronger and more stable than the sheared shale or gouge zones encountered in the drill holes.

Unconfined compression testing of the graywacke yielded high values; however, it must be recognized that the tested samples only represented the best rock at the site.

The drill cores were observed to contain black sheared, slaty shale fragments up to several inches in size. The graywacke and sandstone beds commonly are 1 to 10 feet in thickness, although drill hole LC-1 encountered a sequence about 100 feet thick.

Black Shale Unit. The black shale bodies occurring at the site are commonly lenticular and narrow and completely surrounded by graywacke beds. The original orientation and relationship to adjoining beds has been destroyed by shearing which presumably accompanied the folding. Most of the shale bodies have been thoroughly fractured and sheared by folding and compression between the more competent graywacke and sandstone beds. The shale is slightly metamorphosed and the more siliceous zones have been termed slaty shale. This unit has been mapped with the unit described below.

Sheared Black Shale and Minor Sandstone. This unit could be described as sheared shale containing minor lenticular sandstone bodies. The apparent explanation for the observed relationships is as follows. A sequence of shale containing thin beds of sand was subject to shearing prior to induration of the sand. The shearing disrupted the sand beds forming the discontinuous lenticular bodies of sandstone enclosed in the sheared shale matrix. The peculiar shearing or fractured pattern developed in the sheared shale of this unit is also seen in the previously described black shale unit.

Interbedded Sandstone and Shale. Outcrops of sandstone interbedded with shale in approximately equal amounts were observed on both abutments. This unit grades into the massive sandstone unit. The unit is overall quite similar to the massive sandstone unit except that the latter contains more and larger sandstone beds.

Conglomerate. Three beds of siliceous conglomerate occur upstream from the embankment on the right abutment. The conglomerate contains rounded pebbles and cobbles, to 3 inches in long diameter, of chert, greenstone, and dark volcanic rocks.

Minor outcrops of cherty and siliceous slaty shale were observed just downstream from the site. These beds are minor in relation to the other units and so will not be included in the report.

Landslides

Active landslides are exceedingly common throughout the Coast Range Province. Many extensive slides containing enormous yardages of debris have been mapped along the Eel River canyon. In the vicinity of the site five active landslides and two apparently stabilized and inactive slides were mapped (see Plate 46).

The most serious landslide hazard consists of an area of actively unstable ground underlying about half of the proposed spillway on the right abutment. This steep slope consists of numerous slumps and scarps. Heaps of massive sandstone blocks which have spalled from fresh scarps are present. Important features of this area are the steepness of the slope, moderate tree cover, and localized effect of the scarps and slumps. This, plus the fact that in-place ribs of sandstone are present, suggests that this slide area is of relatively shallow depth and probably is not subject to movement as a coherent unit.

Another active landslide occurs near the top of the spillway. This spillway area is covered with heavy vegetation and soil and potentially unstable ground may extend within it. A small active landslide is present at the upstream toe of the dam.

Another landslide in the vicinity of the site is apparently inactive and is located almost along the proposed axis of the dam. This slide appears very old and stabilized and the preliminary exploration did not reveal that this feature would prove a construction problem. Drill hole LA-2 put down near the axis into this slide revealed considerable broken and sheared material which is presumed to be slide debris. Careful future studies should be done on this feature to assess its importance in the design of a high dam at this site.

Exploration

The exploration program consisted of eight NX size diamond drill holes with a total footage of 1,077.6 feet. The average recovery for all the holes was 66 percent. The drilling program consisted of two intersecting channel holes, three right abutment and two left abutment holes, and one hole in the spillway area. All holes were water tested at as many depths as possible. A summary of the results of diamond drilling and water testing at Bell Springs damsite is presented on Table 26.

Foundation Conditions

Right Abutment. This abutment was explored with two holes, RA-2 and RA-3. Hole RA-1 was drilled from the location of RC-1 and thus did not reveal any features other than general lithology. The abutment appears to present no severe foundation problems although the shale and shear zones will require rather deep stripping (20 to 30 feet). These shale and shear zones are interbedded with relatively strong sandstone and graywacke and differential stripping may be necessary. The weak zones (shale and sheared material) appear to be rather deeply weathered as evidenced by RA-2 and RA-3. The shear and broken rock zones encountered in these holes would not appear to constitute a stability problem inasmuch as they are closely confined by resistant sandstone beds. The sandstone beds appear to be weathered to irregular depths. Although the shale and shear zones should accept little or no grout, a thorough grouting program should be planned to seal the fractured sandstone beds.

Channel Section. The channel section contains a random scattering of gravel and sand deposits. This material should be removed in the impervious core zone to disclose the nature of the bedrock. Further stripping will seldom be necessary except in some shale zones where slaking and weathering has progressed to a considerable extent.

In the random or pervious fill zones of the channel area little preparation, other than irregular stripping to smooth the foundation, is needed prior to fill placement.

Left Abutment. The left abutment appears to present a rather difficult preparation problem. Most of the difficulty stems from the unknown features of landslide on this abutment. Dozer trenches and additional drill holes should be placed in this abutment to clarify the foundation problem.

The exploration program revealed a deep (20 feet in LA-1 and 50 feet in LA-2) weathered zone overlying an interval of blue clayey material containing fragments of shale and graywacke. This clayey zone appears to represent the lower contact of a landslide. It is not known whether or not hole LA-2 completely penetrated this landslide; however, core recovery did improve slightly toward the bottom of the hole.

Further exploration is needed to disclose the proper treatment for this abutment. It is tentatively proposed that about 30 feet be removed beneath the impervious section and about 10 feet from beneath the random or rock fill zones.

The grout take should be negligible in the clayey material; however, the fractured sandstone beds should accept small amounts.

Spillway

The spillway, proposed through a deep cut in the right abutment, will be in dipping beds of sandstone and shale. The sandstone portion can be salvaged for use in the dam. The landslide area underlying the lower half of the spillway is a serious problem. Depth to sound rock will vary but deep stripping should be anticipated. The average depth of slide material is estimated to be about 50 feet. Problems will result from the difficulty of maintaining an open excavation in this ground and the instability induced in the mass by excavation.

Diversion Tunnel

The diversion tunnel at the time of the initial investigation was located through the right abutment. Drill holes RA-2 and RA-3 disclosed zones of weak clayey and sheared material through which the tunnel will probably penetrate. Both the above and the sheared shale units will probably require heavy to moderate support. The thicker sandstone beds are fractured and jointed and will require relatively light support. The downstream portal will fall adjacent to the fractured and faulted hinge area of an overturned syncline and extra support may be necessary here.

Construction Materials

Impervious Material. The best source of impervious material appears to be landslide areas located downstream on the west side of the river within 1 mile from the site (see Plate 47). Preliminary tests, including mechanical analysis and compaction tests, indicated this material to be satisfactory.

Pervious or Rockfill Material. This material must be quarried; however, no exploration or detailed field work to locate a quarry was done during the early investigation. The only large source of gravel suitable for drains or pervious sections are located downstream at Sequoia damsite (see Plate 45). For large quantities of quarry rock the best sources appear to be:

1. Sandstone interbedded with lesser amounts of shale about 1 mile upstream from the site.

2. Greenstone and related rocks located about 5.5 miles southwest of the site between Shell Rock and Iron Peak. This apparently potential source is located along the Spyrock road which intersects U. S. Highway 101 a few miles north of Laytonville.

Smaller quantities of material would be available as follows:

1. Spillway excavation would yield rock suitable for rockfill material; however, the relatively high percentage of shale and other poor material must be removed to render this material free draining. However, a large percentage of this material can be placed as semipervious random fill material in a specially designed zone.

2. A body of greenstone outcrops in a prominent knob about 1.5 miles northeast of the site and could supply some rockfill.

Aggregate. Limited gravels are available along the Eel River both upstream and downstream from the site. These potential aggregates can be brought to the site via the existing railroad; however, the limited quantities available, plus the distance involved, would appear to make these materials rather expensive.

The gravel deposits do contain chert and other siliceous material (including siliceous shale); however, the percentage may be low enough to render them non-reactive.

A better source for aggregate would be crushed sandstone or graywacke from the rockfill quarry area. It may be necessary to import the fine sizes or perhaps they can be processed from the channel gravel deposits.

Conclusions and Recommendations

Embankment foundation problems probably would not prohibit the planned structure. The main source of concern will be the inactive landslide underlying the downstream portion of the left side of the embankment.

The landslide underlying the proposed spillway on the right abutment may necessitate an alternate plan. A previously proposed spillway through the left abutment would cross inactive landslide slope and empty directly at the toe of an active slide on Blue Rock Creek. This alternative does not appear any more satisfactory than the current plan. A more thorough study of spillway alternatives and their geological problems is necessary before a recommendation can be made.

Grouting should be performed beneath the dam and along the abutments; however, very little take is anticipated. Open connected channels through which water might flow through the abutments can only exist in the graywacke and sandstone. No large continuous bodies of graywacke or sandstone would appear to pass completely through the abutments; therefore, no large grouting program is expected.

Rockfill material must be obtained from a quarry, presumably one of those indicated on the construction materials map. Other closer sources might be available; however, no detailed construction materials work has been performed. Impervious material, apparently very suitable, can be obtained from landslide deposits in the vicinity of the site. Exploration of these areas is required to determine quantities available. Aggregate can be manufactured from the quarry operation and the graywacke source would be preferable to the schist. Natural aggregates (stream channel deposits) are available only in limited, thin deposits scattered along the Eel River.

TABLE 26

SUMMARY OF EXPLORATION
OF BELL SPRINGS DAMSITE

Foundation drill hole No.	Date started / Date completed	Location	Elevation (ft.)	Inclination	Total depth (ft.)	Typical water losses	Rocks encountered and geological properties	Percent core recovery (excl. of overburden)
RA-1	7-8-57 / 7-14-57	Right abutment, 130' downstream from proposed dam axis	650	42° N80E	79.1	Interval tested: 50' Loss: 0.22 gpm/ft. At 60 lbs./in.^{2}	Massive sandstone, interbedded sandstone and shale, and sheared black shale.	83
RA-2	7-23-57 / 7-27-57	Middle right abutment, on the proposed dam axis	975	Vertical	97.8	Interval tested: 98' Loss: 0.16 gpm/ft. At atmospheric pressure. No pressure test taken.	Clayey gravels to a depth of 27' overlie massive sandstone interbedded with sheared shale.	62
RA-3	7-30-57 / 8-5-57	Upper hole, right abutment, on the proposed dam axis	1,180	Vertical	101.0	Interval tested: 104' Loss: 0.53 gpm/ft. At 100 lbs./in.^{2}	Approximately 6' of soil overlies weathered sandstone and shale to 35' in depth. Below this is interbedded sandstone, sheared shale, and minor conglomerate.	63
RC-1	6-27-57 / 7-2-57	Right bank, 130' downstream from the axis	660	45° S30W	158.8	Interval tested: 54' Loss: 0.28 gpm/ft. At 130 lbs./in.^{2}	Massive, hard sandstone alternates with sheared black shale and pebble conglomerate.	92
LC-1	6-7-57 / 6-19-57	Left bank, 200' downstream from the axis	660	45° N25E	276.5	Interval tested: 227' Loss: 0.21 gpm/ft. At 170 lbs./in^2	Hard, massive, jointed greywacke is interbedded with sheared black shale. Sheared argillite below 240'.	97

(Continued)

Foundation drill hole No.	Date started / Date completed	Location	Elevation (ft.)	Incli-nation	Total depth (ft.)	Typical water losses	Rocks encountered and geological properties	Percent core recovery (excl. of overburden)
LA-1	8-15-57 / 8-22-57	Left abutment, on axis, about 280' above the channel drill hole	890	50° S55W	95.3	Interval tested: 8.3' Loss: 1.45 gpm/ft. At 150 lbs./in.^{2}	50' of soil and weathered sandstone and shale overlie black shale and sandstone with gouge zones up to 4' in core length.	49
LA-2	9-25-57 / 10-1-57	Middle left abutment, on the axis	1,180	50° S46W	144.3	Interval tested: 8.3' Loss: 1.87 gpm/ft. At 150 lbs./in.^{2}	50' of soil and weathered sandstone and shale overlie sheared black shale, sandstone, and clay gouge seams.	28
S-1	8-26-57 / 9-6-57	Spillway	1,310	Vertical	124.8	Interval tested: 8.8' Loss: 0.22 gpm/ft. At 150 lbs./in.^{2}	50' of soil and weathered rock overlie interbedded sandstone and shale with some gouge zones.	57

TABLE 27

GEOLOGIC CHARACTERISTICS OF DAMSITES

Lower Eel River

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
Sec.8 and 9, T5S,R6E,RB&M	Island Mt.	Eel River	The foundation rocks are hard, layered sandstone and shale of the Franciscan formation. Bedding strikes across the channel and dips downstream. No joint systems or faults were observed. Several slides occur on a gentle slope upstream from the left abutment.	Estimated for concrete and earthfill dams 300' high. Right Abutment -- Concrete: 15' bedrock. Earthfill (impervious section) Remove loose rock and shape. Channel Section -- Concrete: 3' beneath channel fill. Earthfill (impervious section) Shape only. Left Abutment -- Coocrete: 5' of soil and loose rock and 30' of bedrock. Earthfill (impervious section) 5' soil and loose rock and 5' of fractured bedrock.	An overpour spillway may be used on a concrete structure. A spillway may also be located around the left abutment.	Rock in the right abutment appears most favorable for tunneling.	I-None available in immediate vicinity. P-Streambed gravels available in small quantities, from scattered river bars. RF & RR-Selected local bedrock can be quarried. Rock being quarried near Island Mt. R. R. Station.	Moderate	Concrete dam. Earthfill dam.	
Sec.13 and 14, T22N,R14W, MDB&M	Woodman	Eel River	The site is underlain by hard, fine grained, massively bedded sandstone and crushed and sheared bedded mudstone. Jointing is present on the right abutment. A slide is present on the left abutment.	Estimated for rockfill and gravity dams 500' high. Right Abutment -- Gravity dam: 20' of jointed, weathered rock. Rockfill dam: (impervious) 15' of jointed, weathered rock. Rockfill dam: (pervious) 7' of jointed, weathered rock. Channel Section -- Gravity dam: 5' of jointed rock to shape. Left Abutment -- Gravity dam: 25' of weathered rock and soil. Rockfill dam: (impervious) 40' of slide and weathered rock. Rockfill dam: (pervious) 30' of slide and weathered rock.	An overpour spillway is recommended. The plunge pool may have to be blanketed.	A diversion tunnel will be through the right abutment in sandstone.	I-Landslide debris 2 mi. oorthwest. P-None present in sufficient quantity. RF & RR-Sandstone or greenstone.	Moderate	The site appears good for a rockfill or concrete dam 150' high. Maximum possible height about 450'.	

CHAPTER X. KLAMATH RIVER PROJECTS

The only project considered thus far for development of Klamath River is Humboldt Dam and Reservoir. Investigation of this site was at a reconnaissance level but did include a seismic survey. Plate 48 shows the general geologic conditions at Humboldt damsite. The geology of other damsites on the Klamath River which were investigated less thoroughly are briefly described in tabular form on Table 28. This table includes Hamburg, Happy Camp, Red Cap, State Creek, Mettah Creek, Blue Creek, Jackman, and Hornbrook damsites.

Humboldt Damsite

The proposed Humboldt damsite on the Klamath River lies about 1 mile south of the Del Norte-Humboldt County line in Sections 3 and 10, T12N, R2E, HB&M. The damsite area is covered by the USGS 15-minute Tectah Creek quadrangle with a scale of 1:62,500 and a contour interval of 50 feet.

Access to the site is by boat only; however, a rough jeep road leads to the mouth of Blue Creek about 1.75 miles upstream from the right abutment. Another unmaintained logging road leads to the stream channel about 2 miles upstream from the left abutment. The proposed spillway saddles located 3 miles to the west of the site can be reached over recently constructed logging roads.

Reconnaissance geologic studies of the damsite consisted of a brief evaluation of the foundation conditions, the suitability of the saddle spillway, the availability of construction materials, and a brief geophysical exploration program in the channel area for the purpose of determining the depth of alluvium.

The present plans call for a Humboldt Dam 740 feet high with a gross reservoir capacity of about 15 million acre-feet. The embankment will consist of an impervious core with a transitional zone of river alluvium and a rockfill shell. The total volume of fill material will be approximately 135 million cubic yards. The compacted fill volumes of the three zones are as follows: (1) impervious core - 31 million cubic yards, (2) transitional (alluvium) - 53 million cubic yards, and (3) rockfill - 51 million cubic yards.

Diversion during construction will be accomplished by two 50-foot diameter tunnels around the right abutment. A gated, chute-type spillway will be located in a saddle about 3 miles west from the site.

Geology of the Site

The area in which the damsite is located is underlain by the Franciscan formation of Jura-Cretaceous age. Reconnaissance geology of the site and geologic sections, based on geophysical data, appears on Plate 48.

The formation as observed in this area consists of a blocky, moderately jointed sandstone which is grey on fresh surfaces and becomes tan to brown when weathered. The sandstone is moderately well indurated and is very hard when fresh. Shale interbeds were observed, but generally make up less than 5 percent of the entire unit. The shale interbeds are generally thin, from 6 inches to about 4 feet in thickness. The sandstone is generally massive and individual beds may vary from 3 or 4 feet to 20 feet or more in thickness.

The intensity of weathering above the active channel is very high, owing to heavy precipitation and a dense vegetation cover. Outcrops at the site are found only in stream channels and in roadcuts. Weathering may extend to depths of 100 feet or more on the ridge tops, but is shallower on the side slopes. Bedrock exposures along the river channel extend locally up to 200 feet above the water surface.

The geologic structure of the immediate damsite area is generally homoclinal. The beds have an average strike of N15-20W and dip of about 45 degrees to the NE. The channel of the river at the proposed damsite follows the general strike of the strata. Minor faulting and shearing are quite common throughout the area. However, the closest known major fault lies about 2 miles to the NE and parallels the river. No major fault zones were observed within the dam foundation on this reconnaissance trip, but it is possible that a fault may exist within the damsite area, i.e., in the channel beneath the alluvium.

No major landslides were noted, but small surficial slides are quite common along the banks of the river. Landslides are therefore not expected to be a major problem during construction of the dam.

Foundation Conditions

The major problem associated with the damsite is the wide channel section. The channel averages about 750 feet in width and is entirely filled with alluvial material. A limited seismic exploration study was conducted in the stream channel in September 1963, in order to determine the total depth of the alluvial fill. The geophysical exploration proved to be inconclusive in part, for the maximum depth of 175 feet obtainable with a 550-foot spread fell short of the maximum depth of the alluvium, in 11 of 20 shot points (see Plate 48). Further geophysical work is contemplated in the Humboldt damsite channel section using longer spreads where possible in order to reach the bedrock surface.

The estimated possible total depth of fill used in the preliminary design of the structure was 300 feet. The selection of this very high figure was based on the magnitude of the sea level fluctuation during the last two Ice Ages which occurred 45,000 and 15,000 years ago, and during which the sea level rose by approximately 370 and 250 feet, respectively. As the sea level rose, the sedimentary load of the river was deposited in the river canyon until the entire submerged portion was filled. This is a rather oversimplified description of a process that was probably much more complex and involved simultaneous uplift of the land surface during the rise of the sea level.

The interpretation of the seismic depth data and the study of cross-sections along shot points indicates that the depth of alluvium may be somewhat shallower than the maximum used in preliminary design and may be on the order of 200 to 250 feet.

It is also entirely possible that the Klamath River follows a large fault zone that could be hidden under the channel; however, there are no surface indications of this condition. Numerous small faults and shears were observed in the banks bordering the channel. Most of these are minor and some are partially or completely healed and should not constitute a hazard during construction operations. Drilling within the channel should reveal whether or not any major fault zones are present and ascertain the depth of fill.

The geologic knowledge of both abutments is confined to the base of the slope about 100 feet above the channel. Above this elevation there are no outcrops and the vegetation cover is extremely dense.

The base of the right abutment consists of massive sandstone which dips into abutment slope at about 45 degrees. Minor ravines which follow small shear zones cross the slope within the area of the fill. A shale unit about 4 feet thick with its strike parallel to the river follows the water level for a short distance at the base of the right abutment.

The left abutment has an average slope of about 35 degrees and the projected apparent dip of the sandstone strata is nearly parallel to the canyon slope. Some construction difficulties during foundation preparation caused by sliding and slipping along the bedding planes should be anticipated. The left abutment consists of the same rock units as the right, based on exposures near the channel. No outcrops were found above the stream and the overburden appears to be very thick.

Stripping Estimates

Abutments	Channel
Impervious	
Remove 70 feet of overburden and deeply weathered, decomposed bedrock.	Remove all channel fill up to 300 feet with an average depth of about 250 feet. Minor bedrock stripping and shaping. Consideration should be given to a grout curtain cutoff with relief wells downstream of the embankment in lieu of a deep cutoff excavation.
Pervious and Transition	
Strip all overburden and loose rock - average depth of 20 feet on both abutments.	10 feet of alluvium and slopewash.

Diversion Tunnels

Two 50-foot diameter tunnels have been suggested for diversion purposes during construction of which one or more is to be maintained for conveyance of water to the powerhouse after completion of the dam.

Right Abutment Tunneling Conditions. Most of the rock will consist of moderately blocky, fractured sandstone. Some shear zones may be encountered that may be up to 50 feet wide. Many minor shears that are partially healed will also transect the tunnels and water problems can be expected in the shear zones. Bridging time in a tunnel of this size in the sandstone will be short and will necessitate support to protect workers and equipment. It will be necessary to install 100 percent lining and support.

Left Abutment Tunneling Conditions. Tunneling conditions in the left abutment appear to be somewhat better than in the right abutment, as the shear zones appear to be less numerous. Shorter diversion tunnels are more feasible in this abutment, although it would still be necessary to swing the alignment back into the abutment to obtain maximum cover where shear zones are suspected. It should be noted that proper spacing must be maintained if a series of tunnels are driven in the left abutment. This spacing factor may have to be increased where the tunnels parallel the strike of the beds due to the 45 degree dip of the sandstone-shale units.

Water problems can be expected to be the same as those in the right abutment.

Spillway

The proposed spillway is located in a saddle about 2.5 miles west of the axis. The elevation of the saddle is just over 900 feet, requiring an excavation 220 feet deep for a dam with normal pool elevation of 800 feet. Another possible spillway site exists at the saddle between the North Fork Ah Pah Creek and McGarvery Creek. The saddle elevation is 850 feet; however, surrounding steep slopes and shallow stream gradients at this location may result in a higher excavation volume. Both saddles are underlain by deeply weathered, intensely fractured sandstone with shale interbeds. Common excavation methods would be applicable to a maximum depth of no more than 50 feet and the remainder of the excavation will be by hard rock methods. Side slopes are expected to stand on 1:1 with berms every 50 feet.

The attitude of the strata is northwest with an eastern dip of 30° to 50°. Under these conditions the western cut slope will nearly coincide with the dip and will tend to be more unstable. It may become necessary to flatten the slope to at least the same angle as the prevalent dip to preclude large scale sliding.

The excavated material is expected to be suitable for the transitional and rolled rock sections in the proposed dam.

Construction Materials

Impervious Material. The principal source of impervious fill within haul distance from the site appears to be slopewash and residual soil derived from weathering of the Franciscan rock units. No exploration or detailed study was made during the reconnaissance stage of the investigation; however, based on the present knowledge, sufficient volume of fill can be obtained within a 5-mile radius from Humboldt damsite.

Rock. Obtaining fresh rock for the construction of the dam should present no great problems. A large bluff (BM-142) immediately downstream from the dam is a possible low-level source of quarry material. Another low level source is found upstream from the site just above the mouth of Blue Creek. At this place both abutments are composed of hard, massive sandstone extending toward the river as sharp ridges. It may be possible to use Starwein Ridge or the ridge on the left abutment as a source of high-level quarry material. Both appear to have suitable sandstone rockfill material.

Gravel. The Klamath River channel is covered by extensive deposits of alluvium suitable for the transitional section of the embankment. Seismic exploration indicates that the alluvium is at least 250 feet thick at the site and is considerably deeper downstream. Although only the upper portion of the channel fill will be economical for the embankment, the vast quantity present should satisfy the requirements for the highest dam proposed during this investigation. In the preliminary design sufficient quantities of this material were assumed to be present within 6 miles up- and downstream from the site.

Powerhouse Location

There are several possible sites for the construction of powerhouse facilities. Immediately downstream from the toe of the dam on the left abutment is one possible site. This area is covered by terrace deposits to an elevation of about 75 feet above the water surface, but removal of these during construction of the dam should expose massive sandstone suitable for foundation purposes. Further downstream on the left abutment (west of BM-142), outcrops in the river channel would indicate that this area would also be suitable for the powerhouse location. On the right abutment the most suitable location would be near BM-115. This would necessitate driving at least one of the diversion tunnels through the right abutment and would increase the length of the tunnel by about 3,000 feet.

General Remarks

Clearing of the reservoir area will be a large item in the construction of this dam. Much of the ground up to 700 feet elevation is heavily forested with redwood and fir. Logging operations presently taking place in the area are decreasing the amount of clearing needed and will continue to do so. There are few houses and roads that will need relocation in the lower reaches of the reservoir.

Conclusions and Recommendations

The Humboldt damsite is believed to be the most suitable location for the construction of a high earthfill or rockfill dam within the lower reaches of the Klamath River. This opinion is based upon geologic and topographic information gained during a brief investigation. Further investigation is necessary before any specific conclusions concerning the site can be made. This should include detailed geologic mapping of the site and surrounding area, followed by prelinimary drilling in the channel and abutments of the damsite, and in the proposed spillway location. The areas of the tunnel portals and the powerhouse location should also be investigated in the early stage drilling program. A program of this nature is necessary to locate any zones of weakness due to faulting or shearing within the areas of construction.

TABLE 28

GEOLOGIC CHARACTERISTICS OF DAMSITES

Klamath River

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
SE 1/4 Sec.30, T11N,R3E, HB&M	Mettah Creek	Klamath River	The site is underlain by hard, medium grained sandstone, conglomerate and slate. There is minor jointing.	Estimated for a 200' high concrete gravity dam. Right Abutment -- 15' in sandstone, 25' in slate. Channel Section -- Channel fill stripping about 150'. Bedrock stripping is 5' to shape. Left Abutment -- 10' to shape.	An overpour spillway is recommended.			Moderate	Concrete gravity.	
Sec.15,22, T12N,R2E, HB&M	Blue Creek	Lower Klamath River	The site is underlain by hard, fine grained Franciscan sandstone with minor amounts of inter-bedded shale. Shearing and joints are present. Intersecting joint sets result in a blocky structure. Shears to 1' in width contain broken rock and occur chiefly along bedding planes.	Estimated for a concrete dam about 150' high. Right Abutment -- Strip exposed bed-rock at the abut-ment base 15' for a height of 12' above the low water surface. Above this strip 12' - 15' of mantle and 20' of jointed rock. Channel Section -- 20' of stream gravel and boulders. 10' of rock beneath channel fill. Left Abutment -- 3' of residual mantle and 15' of rock.	The left abutment offers the most favorable location for a spillway.	An outlet tunnel could be located through the left abutment. Lining and support will be required.	I & P-No suitable earthen construction materials are within reasonable distance of the site. RF & RR-Quarry rock in vicinity of site.	Moderate	Concrete gravity, slab and buttress with overpour spillway.	
Sec.12,T10N, R3E,HB&M	Jackman	Klamath River	The site is underlain by meta-morphosed sediments. Bedding with variable attitudes is present on the left abutment. The right abutment is massive. A terrace of large boulders and sand occurs on the right abutment.	Estimated for a masonry type structure. Right Abutment -- Terrace stripping: 3' sand, 20' boulders, 10' jointed rock. Remainder of abutment: 5' soil and loose rock; 3' - 15' fractured and weathered rock. Channel Section -- 15' channel fill, 8' jointed rock. Left Abutment -- 3' soil and rock, 12' weathered rock.	For a concrete structure, a well protected overpour spillway is most suitable. A side channel spillway could be used high on the left abutment.	The left abutment appears most favorable for an outlet tunnel. Moderate sup-port and lining would be necessary.	I & P-No borrow areas for earthfill materials available. RF & RR-May be quarried at site.	Moderate	Concrete gravity.	

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
Sec.31,T46N, R10W,MDB&M	Hamburg	Klamath River	Principally foliated chlorite schist which is highly contorted and moderately sheared. General dip downstream into left abutment. Joints moderately developed. Quartz veins prominent. Weathering shallow. No major faults in vicinity.	Moderate soil cover on abutments is rich in humus; moderate rock stripping beneath this. Medium deep channel fill.	Considerable protection needed at base of spillway to prevent plucking of jointed bedrock.		I-Probably no large quantities in vicinity. P-Spoils and quarry rock only. RF & RR-Local rock suitable. Local rock probably suitable. Aggregate-From river channel and Scott Valley if needed.	Low	Concrete gravity.	Moderate grouting probably necessary. Comprehensive exploration program needed, including testing aggregates.
Sec.33,T16N, R7E,HB&M	Happy Camp	Klamath River	Principally a very hard, slightly sheared phyllite with occasional slates and metasandstones. Many granitic dikes cut through rock mass. Joints are prominent and occur both in sets and at random. Some quartz veining. Canyon walls are stable. Beds appear to dip steeply upstream into left abutment but are often distorted and folded.	Channel fill concealed by water at all seasons. Overburden light on abutments; depth of rock stripping moderate to light over entire site.	Considerable protection should be furnished the bedrock at the toe of the spillway where discharge into the river channel occurs. Blocky rock in that area.		I-Some from Weaverville formation and thin residual soils on hillsides nearby. Limited. P-Dredger tailings in valley around community of Happy Camp. Spoils. Quarry rock. RF & RR-Can be quarried locally. Aggregate-Local stream gravels in limited quantities and dredger tailings from vicinity of Happy Camp.	Low	Concrete gravity. Rockfill.	Some dental work would be needed in areas of weak rock. Moderate to heavy grouting likely. No previous exploration has been done but much is needed. Aggregates should be tested.
W 1/2 Sec.10, T10N,R5E, HB&M	Red Cap	Klamath River	The site is underlain by hard, fine grained greenstone which is foliated and jointed in several sets.	Estimated for a concrete gravity dam 750' high. Right Abutment -- Average 40' of jointed rock beneath about 2' of loose rock and soil. Channel Section -- Channel deposits average about 10' in depth. Bedrock stripping: 20'. Left Abutment -- 5' of soil and loose rock and 40' of jointed bedrock.	An overpour spillway may be used on a concrete dam. A small terrace on the nose near the left abutment is also suitable for a spillway.		I-None available. P-None available. RF & RR- Quarried rock near site.	Moderate	Concrete gravity.	
Sec.19,T10N, R5E,HB&M	Slate Creek	Klamath River	Right abutment composed of serpentinized ultra-basic rock with some diorite in fault contact near the stream channel. Serpentinized rock is blocky, fractured and sheared, and prone to sliding when wet. Faults are present in the stream channel from the proposed axis to the upstream toe with clay gouge and talc schist present. Left abutment composed of slate phyllite with some sandstone and green schist all striking NE and dipping into the abutment. Heavy soil cover and a large talus slide are present on upper slope. Two prominent faults on lower portion of this abutment.	Light to moderate soil cover on abutments, increasing on upper slopes. Rock stripping in entire foundation area should be moderate becoming heavy on upper slopes. Channel bottom concealed by water at all seasons. Depth of channel fill may be more than 40'.	Cut would be in serpentinized ultra-basic rocks below a probable depth of about 10' of soil and weathered rock. Most of spillway channel would have to be lined. Most of hardrock spoils could be recovered for rockfill.		I-Difficult to obtain nearby in large quantities. Nearest possible source is at Orleans Flat 2 mi. upstream. P-Spoils. Quarry rock. River gravels. RF & RR-Could be quarried locally in large quantities. Only a little quarry waste. Aggregate-River gravels and nearby tailings. Also unworked auriferous gravel deposits (small).	Low to moderate	Rockfill.	Site mapped in detail and explored with drill holes as follows: 4Nx left abutment; 3Nx right abutment; 2Nx beneath channel from each bank and 3Nx along spillway. Spillway explored by bulldozer cuts. Special treatment required along faulted channel section. Slide near spillway requires remedial work. Grout take moderate to high.

TABLE 28 (continued)

Location number	Site name	Stream	Foundation conditions	Stripping	Spillway	Diversion tunnel	Construction materials	Seismicity	Feasible structures	Special problems
NE 1/4 Sec.5, T46N,R6W, MDB&M	Hornbrook	Klamath River	The site is underlain by hard, fine grained, massive metavolcanic rocks. The rocks are moderately jointed. There is light shearing. Foliation dips downstream and slightly into the right abutment.	Estimated for rockfill and concrete gravity dams 350' high. Right Abutment -- Rockfill -- Impervious section: 3' of soil and loose rock, 4' jointed rock. Pervious section: About 2' of loose material by washing. Concrete gravity -- 25' of rock beneath overburden. Channel Section -- Bedrock stripping. Rockfill -- Impervious section: Shaping only. Pervious section: Shaping only. Concrete gravity -- 15' of jointed rock. Channel deposits average about 25' in depth. Left Abutment -- Rockfill -- Impervious section: 8' total, 1/2 common excavation, 1/2 hardrock. Pervious section: Overburden and shaping only. Concrete gravity -- 25' of jointed rock beneath overburden.	Overpour may be used on a concrete structure. A saddle behind the right abutment is a satisfactory spillway site.		I-Available at Hornbrook Flats, maximum haul distance is 3 mi. P-Spoils, gravel in channel, quarry rock locally. RF & RR-Spillway cut spoils or local quarrying.	Low to moderate	Combination earth and rockfill. Rockfill. Concrete gravity.	

ATTACHMENT A

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ATTACHMENT B

ENGINEERING GEOLOGY OF LANDSLIDES ALONG THE EEL RIVER

The Eel River system, upstream from Sequoia Damsite, is characterized by broad canyons and rugged, grassy or brush- and timber-covered mountains. In general, the rocks exposed in this area all belong to the Franciscan group of Jura-Cretaceous age, and consist of thick beds of hard graywacke sandstone with interbedded, less competent beds of black fissile shale. Associated with these sedimentary series are beds of conglomerate, irregular lenses of chert, scattered intrusions of greenstone and serpentine, and masses of schist.

The rocks of the Franciscan group produce a type of topography that is conductive to a particular type of landslide; i.e., the earth flow type. Where these slides are situated above reservoirs they could move slowly into the reservoirs and gradually reduce storage capacities as well as endanger structures associated with the dam or with tunnel inlets. Also, landslides occurring upstream from the reservoir provide a large supply of sediments to be carried in suspension by the stream into the reservoir. Another aspect of the landslides, which is not evaluated in this study, is the effect of landslide-triggered waves in reservoirs.

Purpose and Scope of Investigation

This investigation has been undertaken to estimate the quantity of unstable material that may move into the proposed reservoirs planned on the Eel River. Table B-1 lists the proposed reservoirs used in connection with this study.

A study of aerial photographs of the Eel River system enabled the preliminary plotting of some 200 slides on a series of strip maps at a scale of 1:31,680. Over half of these slides were field checked to define the limits of moving ground more accurately. It was not possible to field check all of the slides owing to a lack of time and the inaccessibility of the area.

The field checked slides have been delineated on strip maps in an unpublished office report (see Attachment A). Each slide has been assigned a number according to its distance in miles upstream from Sequoia Damsite. The slides located along tributaries to the Eel River have been numbered according

TABLE B-1

PROPOSED RESERVOIRS, EEL RIVER

Dam	Location	Streambed elevation	Range of dam heights used
Sequoia	Sec. 6, T2S, R4E	150	300 to 700
Bell Springs	Sec. 30, T24N, R14W	650	200 to 600
Woodman	Sec. 11, T22N, R14W	850	200 to 500
Willis Ridge	Sec. 32, T21N, R13W	1,025	225 to 625
English Ridge	Sec. 6, T19N, R12W	1,175	175 to 475
Marshall	Sec. 1, T18N, R12W	1,350	200 to 500
Benmore	Sec. 13, T18N, R11W	1,550	200 to 500
Dos Rios	Sec. 4, T21N, R13W	950	200 to 600
Spencer	Sec. 1, T22N, R12W	1,350	200 to 400

to the distance in miles above their confluence with the Eel River. In addition, they also carry a letter designation relating to the particular tributary. Also appearing on the strip maps are mileage ticks showing the distance above Sequoia Damsite on the main stem, and the distance above the confluence of the tributaries.

Previous Investigations and Reports

The only known previous investigation of landslides along the Eel River is an office report undertaken for the Northwestern Pacific Railroad by John Melhase in 1938. A copy of this report, along with supporting photographs and basic data, is on file in the Northern Branch Geology Unit. The general geology of the Eel River system is covered in California Division of Mines Bulletin 179 titled "Geologic Reconnaissance of the Northern Coast Ranges and Klamath Mountains" and also on the Redding and Ukiah sheets of the "Geologic Map of California."

The Nature of Eel River Landslides

Landslides along the Eel River occur both in areas underlain by highly weathered and sheared sediments of the Franciscan group and in areas of weathered serpentine. The surface expression of the slides is generally quite similar, regardless of the nature of the underlying rock.

In the areas underlain by Franciscan sediments, the slides generally occur in grassy areas having a clayey soil. The soil type usually has good to rapid surface drainage and poor subsurface percolation rates. It may be classed as a moderately permeable to relatively impermeable soil. The area receives an average of 50 to 60 inches of precipitation per year. This combination of fairly high rainfall and poor subsurface drainage gives rise to areas of unstable ground.

Landslides developed in areas of serpentine are not as numerous due to the limited extent of the serpentine bodies adjacent to the proposed reservoir sites. In general, the soil developed on this rock type is fairly similar to that occurring in landslide areas of Franciscan sediments. The soil is essentially a clay having moderate to rapid surface runoff and poor subsurface drainage.

The landslides along the Eel River system cannot be analyzed by the usual method of slope stability formulae, since they do not fall along a slip circle. Instead, the slides more closely resemble earth or debris flows, or possibly mud and earth glaciers, since they exhibit such glacial phenomena as pressure ridges and terminal and lateral moraines. The zone of movement of these slides is limited mainly to the saturated overburden and weathered rock. Hence, the depth of an individual slide would not be of very great magnitude as compared with its areal extent. This fact is borne out from the various exposures of in-place bedrock in some of the slides.

The movement of a quasi-stable slide mass is apparently directly related to the amount and duration of precipiation. This is due to the fact that the effect of a saturated condition in the soil mass will tend to lower the normal component of intergranular pressure, due to the buoyant effect of the water, and raise the tangential component, due to the added weight of the water. By lowering the normal component and increasing the tangential component, the safety factor becomes reduced to a point where sliding may start.

Volume of Landslide Material

An estimate of the quantity of sliding material was made by assuming various water surface elevations in the proposed reservoirs and determining the upslope acreage of each slide above each water surface elevation.

The areas were then totaled for each reservoir at various water surface elevations. An arbitrary depth of 25 feet was assigned to each slide in lieu of the actual, unknown depth to arrive at an estimate of the volume of each slide. The total upslope volume for each reservoir at each water surface elevation was then related to the respective storage capacity at that elevation. These data apply to that material considered to be in a quasi-stable state at this time. In addition to these quantities, there exists a large and unknown amount of material composed of the same type of soil and weathered rock that is presently in equilibrium. This latter material may begin to slide at some time in the future if one of the following two conditions occurs: (1) if the material is situated above the head of an active slide, the head will slowly advance upslope, thus causing new ground to start sliding; (2) if an earth slump, or incipient slide, forms on previously stable ground due to either natural or manmade causes.

Rate of Movement

The only data presently available concerning the rate of movement of a landslide in this area are that for Slide No. 27.90. During the period of record, about 2 months, the slide moved approximately 245 feet. This amount of movement is probably close to the average for an active slide. As an overall picture, most slides will be dormant at any given time, and the total amount of seasonal movement of an active slide may vary from a few feet to several hundred feet, depending on the amount of precipitation, the river state, and various other factors. The effect of a fluctuating reservoir on dormant and active slides cannot be determined with available data. However, it may be assumed that any sliding directly due to a reservoir should take place during the first few years of operation.

Conclusions

Landslides along the Eel River present a serious problem to the design of reservoirs, particularly those downstream from the town of Dos Rios. Most such slides occur in areas of Franciscan sediments. The slides are unique in that they do not fall along a slip circle, but are more closely related to earth and debris flows. The rate of flow is apparently directly related to the amount of precipitation. The quantity of moving material varies from 0 percent of the storage capacity for a low dam at English Ridge to a maximum of 11.18 percent for a low dam at Benmore (see Table B-2). With the exception of English Ridge, the higher the dam the lower the percent loss of storage capacity.

<u>Recommendations</u>

In order to more accurately determine the areal and volumetric extent of actual and potential landslides along the Eel River, the following program is recommended:

1. Field checking of all remaining nonfield checked slides so that their limits may be accurately defined.

2. Delineation of areas of potential sliding ground.

3. Determination of the depth of moving ground on various slides through the use of electrical resistivity surveys.

4. Determination of the type of materials making up slide areas through the use of test holes drilled into typical slides. Samples to be obtained from the sliding ground, slip surface, and underlying stable rock. Samples to be tested for permeability, etc.

5. Determination of the type of materials making up the adjacent stable, and adjacent potentially unstable, ground through the use of test holes drilled into these areas. Samples to be obtained for permeability, etc., tests.

6. Movements to be established on several of the larger slides so that rates of movement can be determined.

7. The rate of movement below the surface, or at least the average depth of the active slides, should be determined. Flexible tubing inserted into drill holes within active slides could give at least qualitative data on the depth of moving material.

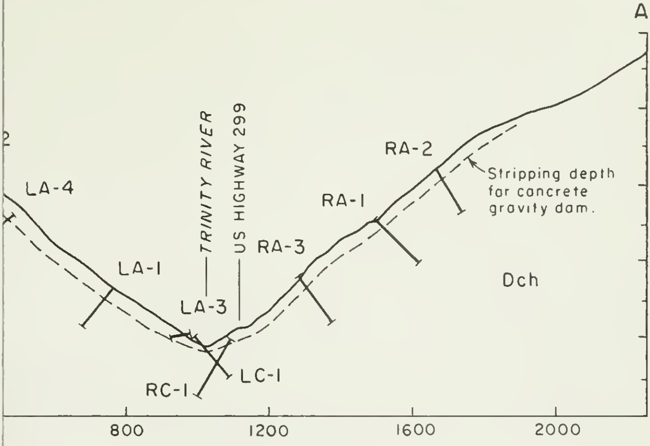
TABLE B-2

VOLUME OF LANDSLIDES AND
LOSS OF STORAGE CAPACITY

Reservoir	Dam height (ft.)	Water surface elev.	Storage capacity (acre-feet)	Area of sliding ground (acres)	Volume of landslides* (acre-feet)	Loss of storage capacity (percent)
Sequoia	300	450	920,000	1,776	44,420	4.83
	400	550	1,900,000	2,413	60,332	3.18
	500	650	3,230,000	2,736	68,400	2.12
	600	750	5,180,000	3,427	85,675	1.66
	700	850	7,500,000	3,279	81,975	1.09
Bell Springs	200	850	130,000	475	11,433	8.80
	300	950	380,000	667	16,673	4.40
	400	1,050	860,000	1,475	36,875	4.23
	500	1,150	1,640,000	1,411	35,283	2.15
	600	1,250	2,840,000	1,304	32,593	1.15
Woodman	200	1,050	220,000	631	15,768	7.18
	300	1,150	620,000	586	14,640	2.35
	400	1,250	1,400,000	540	13,510	0.98
	500	1,350	3,000,000	459	11,493	0.38
Willis Ridge	225	1,250	160,000	79	1,975	1.23
	325	1,350	410,000	73	1,818	0.45
	425	1,450	900,000	74	1,855	0.20
	525	1,550	1,680,000	290	7,258	0.43
	625	1,650	2,900,000	424	10,608	0.38
English Ridge	175	1,350	70,000	0	0	0.00
	275	1,450	250,000	25	620	0.23
	375	1,550	650,000	156	3,910	0.60
	475	1,650	1,420,000	415	10,365	0.73
Marshall	200	1,550	100,000	96	2,403	2.40
	300	1,650	**	253	6,318	**
	400	1,750	**	233	5,825	**
	500	1,850	**	173	4,333	**
Benmore	200	1,750	50,000	223	5,585	11.18
	300	1,850	320,000	173	4,333	1.35
	400	1,950	890,000	140	3,503	0.40
	500	2,050	1,500,000	88	2,193	0.13
Dos Rios	200	1,150	100,000	322	8,038	8.03
	300	1,250	300,000	297	7,420	2.45
	400	1,350	860,000	306	7,660	0.90
	500	1,450	1,980,000	288	7,193	0.58
	600	1,550	4,300,000	527	13,170	0.30
Spencer	200	1,550	115,000	291	7,263	6.30
	300	1,650	510,000	280	7,003	1.38
	400	1,750	1,000,000	228	5,703	0.58

* Based on 25-foot average depth of slides.

** No capacity nor percent loss data available for this water surface elevation.



SECTION A-A'

LEGEND

ch HORNBLENDE META-ANDESITE
HARD MASSIVE, GRAYISH-GREEN META-ANDESITE

elulla
ation

75 STRIKE AND DIP OF JOINTS

90 STRIKE OF VERTICAL JOINTS

20 STRIKE AND DIP OF FOLIATION

70 FAULT, SHOWING STRIKE AND DIP

SHEAR ZONE

SPRING

RA-1 INCLINED CORE HOLE, SHOWING BOTTOM LOCATION

A' GEOLOGIC SECTION LINE

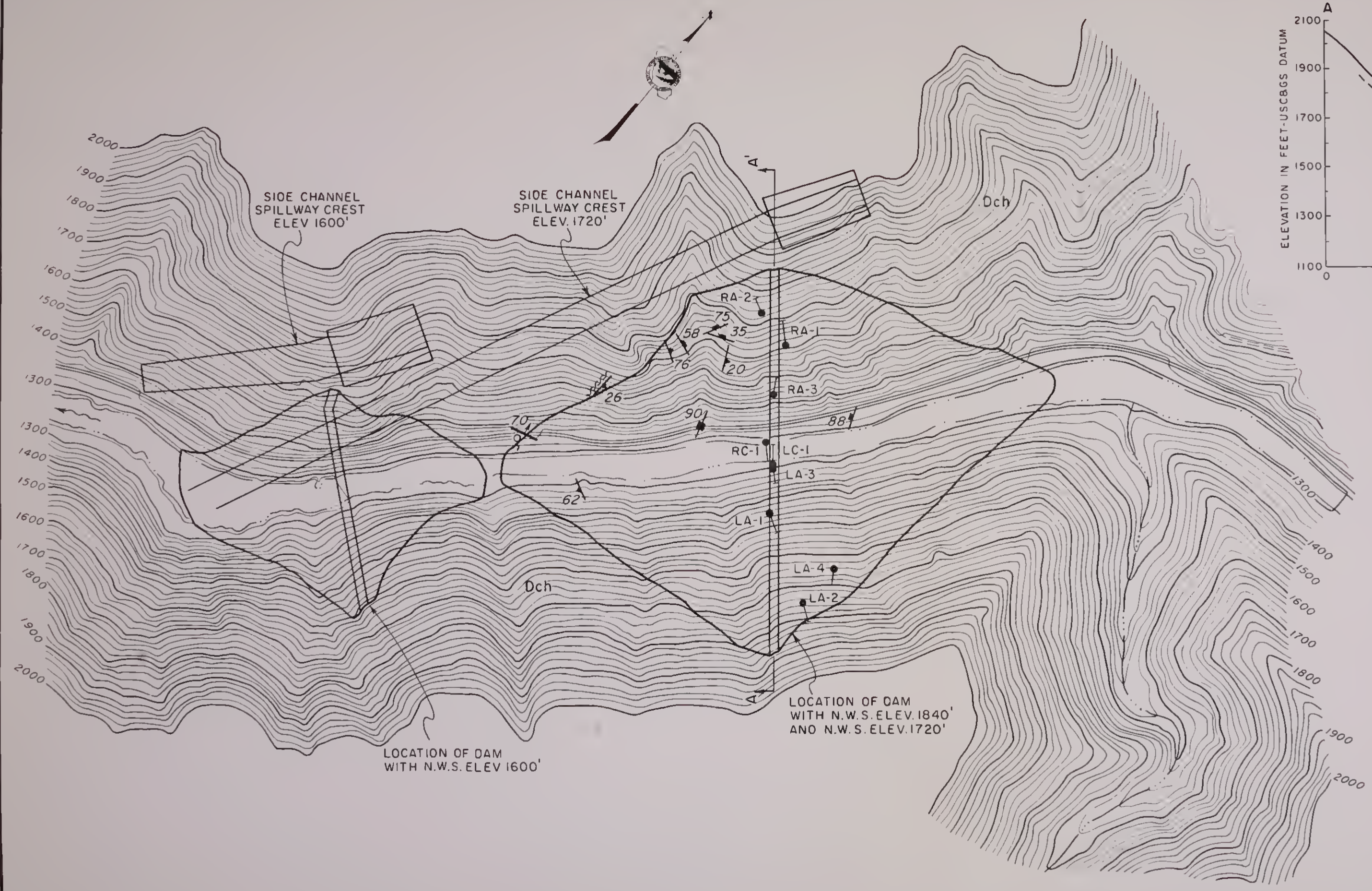
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

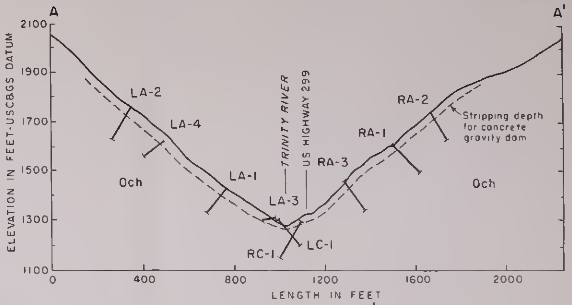
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION
HELENA DAMSITE-TRINITY RIVER

SCALE OF FEET
400 0 400

Contour Interval 20'





SECTION A-A'

LEGEND

DEVONIAN (?)

Dch — Chanchelulla Formation — HORNBLENDE META-ANDESITE
HARD MASSIVE, GRAYISH-GREEN META-ANDESITE

75 STRIKE AND DIP OF JOINTS

90 STRIKE OF VERTICAL JOINTS

20 STRIKE AND DIP OF FOLIATION

70 FAULT, SHOWING STRIKE AND DIP

SHEAR ZONE

SPRING

RA-1 INCLINED CORE HOLE, SHOWING BOTTOM LOCATION

A A' GEOLOGIC SECTION LINE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION HELENA DAMSITE-TRINITY RIVER

SCALE OF FEET
400 0 400

Contour Interval 20'

LEGEND

P-2	PERVIOUS MATERIAL OR CONCRETE AGGREGATE
I-5	IMPERVIOUS TO SEMI-IMPERVIOUS MATERIAL
R-2	ROCK-FILL OR RIPRAP MATERIAL
	BOUNDARY OF BORROW AREA
4 •	LOCATION OF AUGER DRILL HOLE
	AXIS OF PROPOSED DAM

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS BIG BAR AND HELENA DAMSITES

SCALE OF MILES

1 0 1

Contour Interval 50',100'

LEGEND

P-2	PERVIOUS MATERIAL OR CONCRETE AGGREGATE
I-5	IMPERVIOUS TO SEMI-IMPERVIOUS MATERIAL
R-2	ROCK-FILL OR RIPRAP MATERIAL
	BOUNDARY OF BORROW AREA
4	LOCATION OF AUGER DRILL HOLE
	AXIS OF PROPOSED DAM

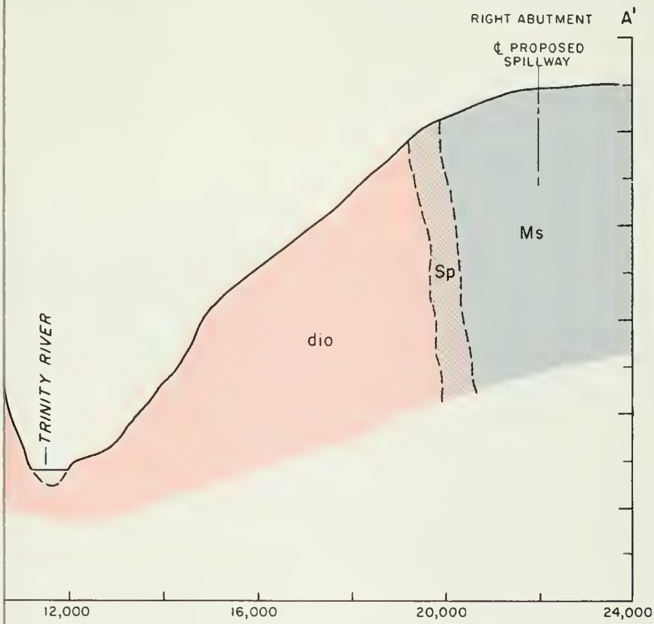
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
BIG BAR AND HELENA DAMSITES

SCALE OF MILES
1 0 1

Contour Interval 50', 100'



LENGTH IN FEET

SECTION A-A'

LEGEND

EBRIS FROM CHINA SLIDE (1890).

ACTIVE CHANNEL OF TRINITY RIVER. GENERALLY SHALLOW
THE PROPOSED SITE. (NOT SHOWN ON GEOLOGIC MAP.)

OW OLDER ALLUVIUM

ALLY DERIVED FROM SHEARED AND DECOMPOSED SERPENTINE

ES OF ALTERED VOLCANIC ROCK

CONTACT ZONE.

SYMBOLS

ED WHERE APPROXIMATELY
CONCEALED.

NT

ECTION OF DIP

ION OR CLEAVAGE-
RATIFICATION

LL HOLE

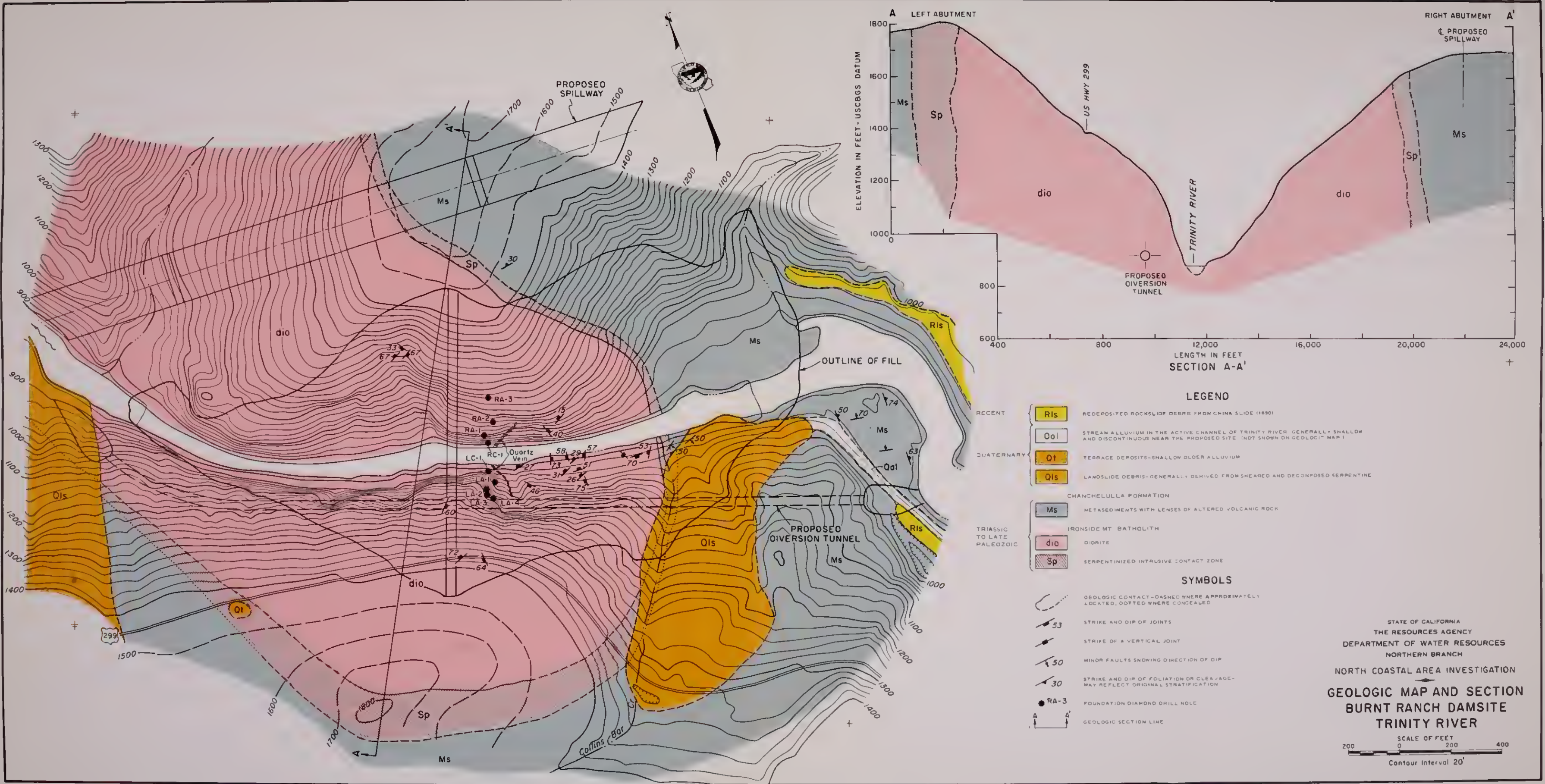
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION BURNT RANCH DAMSITE TRINITY RIVER

SCALE OF FEET
200 0 200 400

Contour Interval 20'



PROPOSED SPILLWAY
OUTLINE OF FILL
PROPOSED DIVERSION TUNNEL
Collins Bar
Quartz Vein
dio
Ms
Sp
Qls
Qt
Qal
Rls
A
A'
LEFT ABUTMENT
RIGHT ABUTMENT
℄ PROPOSED SPILLWAY
US HWY 299
TRINITY RIVER
PROPOSED DIVERSION TUNNEL
ELEVATION IN FEET - USC&GS DATUM
LENGTH IN FEET
SECTION A-A'
LEGEND
RECENT
QUATERNARY
Rls REDEPOSITED ROCKSLIDE DEBRIS FROM CHINA SLIDE (1890)
Qal STREAM ALLUVIUM IN THE ACTIVE CHANNEL OF TRINITY RIVER GENERALLY SHALLOW AND DISCONTINUOUS NEAR THE PROPOSED SITE (NOT SHOWN ON GEOLOGIC MAP)
Qt TERRACE DEPOSITS-SHALLOW OLDER ALLUVIUM
Qls LANDSLIDE DEBRIS-GENERALLY DERIVED FROM SHEARED AND DECOMPOSED SERPENTINE
TRIASSIC TO LATE PALEOZOIC
CHANCHELULLA FORMATION
Ms METASEDIMENTS WITH LENSES OF ALTERED VOLCANIC ROCK
IRONSIDE MT BATHOLITH
dio DIORITE
Sp SERPENTINIZED INTRUSIVE CONTACT ZONE
SYMBOLS
GEOLOGIC CONTACT-DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED
53 STRIKE AND DIP OF JOINTS
STRIKE OF A VERTICAL JOINT
50 MINOR FAULTS SHOWING DIRECTION OF DIP
30 STRIKE AND DIP OF FOLIATION OR CLEAVAGE-MAY REFLECT ORIGINAL STRATIFICATION
RA-3 FOUNDATION DIAMOND DRILL HOLE
A A' GEOLOGIC SECTION LINE
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTION
BURNT RANCH DAMSITE
TRINITY RIVER
SCALE OF FEET
Contour Interval 20'

LEGEND

IMPERVIOUS
SLIDE DEBRIS, COLLUVIUM AND RESIDUAL SOIL DERIVED PRIMARILY FROM SERPENTINE. NO SUITABLE SINGLE SOURCE OF IMPERVIOUS FILL HAS BEEN FOUND AND AN INTENSIVE EXPLORATION PROGRAM IS REQUIRED.

PERVIOUS
RECENT STREAM ALLUVIUM, TERRACES AND DREDGER TAILINGS. SUITABLE FOR PERVIOUS FILL AND CONCRETE AGGREGATE.

ROCKFILL AND RIPRAP
HORNBLENDE DIORITE OF THE IRONSIDE BATHOLITH. GOOD QUALITY ROCKFILL OR RIPRAP.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
BURNT RANCH DAMSITE

SCALE OF MILES
1 0 1

Contour Interval 100'


4 MILES
3 MILES
2 MILES
1 MILE
BURNT RANCH DAMSITE
Hennessy Ridge
Chaparral Mtn
TRINITY RIVER
R 8 E
R 7 E
R 6 E
R 5 E
R 7 E
R 6 E
T 6 N
T 5 N
T 5 N
T 4 N
LEGEND
IMPERVIOUS
SLIDE DEBRIS, COLLUVIUM AND RESIDUAL SOIL DERIVED PRIMARILY FROM SERPENTINE. NO SUITABLE SINGLE SOURCE OF IMPERVIOUS FILL HAS BEEN FOUND AND AN INTENSIVE EXPLORATION PROGRAM IS REQUIRED.
PERVIOUS
RECENT STREAM ALLUVIUM, TERRACES AND DREDGER TAILINGS. SUITABLE FOR PERVIOUS FILL AND CONCRETE AGGREGATE.
ROCKFILL AND RIPRAP
HORNBLENDE DIORITE OF THE IRONSIDE BATHOLITH. GOOD QUALITY ROCKFILL OR RIPRAP.
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
LOCATION OF CONSTRUCTION MATERIALS
BURNT RANCH DAMSITE
SCALE OF MILES
1 0 1
Contour Interval 100'

TUNNELING CONDITIONS ZONES

ZONE	RANGE OF ROCK CONDITIONS	RANGE OF TUNNELING CONDITIONS	PERCENT OF TUNNEL LENGTH
I	HARD AND INTACT TO HARD AND SCHISTOSE	SUPPORT–UNSUPPORTED TO RIBS ON 6-FOOT CENTERS OVERBREAK–NONE TO SLIGHT	66.5%
II	MODERATELY TO VERY BLOCKY AND SEAMY	SUPPORT–RIBS ON 4-FOOT CENTERS OVERBREAK–MODERATE TO HEAVY	22.5%
III	COMPLETELY CRUSHED TO SQUEEZING ROCK, GREAT DEPTH	SUPPORT–CIRCULAR RIBS AT 2-FOOT CENTERS OR LESS OVERBREAK–NONE TO HEAVY	11.0%

NOTES:

1. THE GEOLOGY OF PORTIONS OF THIS MAP HAS BEEN MODIFIED FROM IRWIN (1960), KINKEL AND OTHERS (1956), AND SOUTHERN PACIFIC RAILROAD CO. (1957).

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION CLEAR CREEK TUNNEL No. 2

SCALE OF MILES

1 0 1

Contour Interval 50'

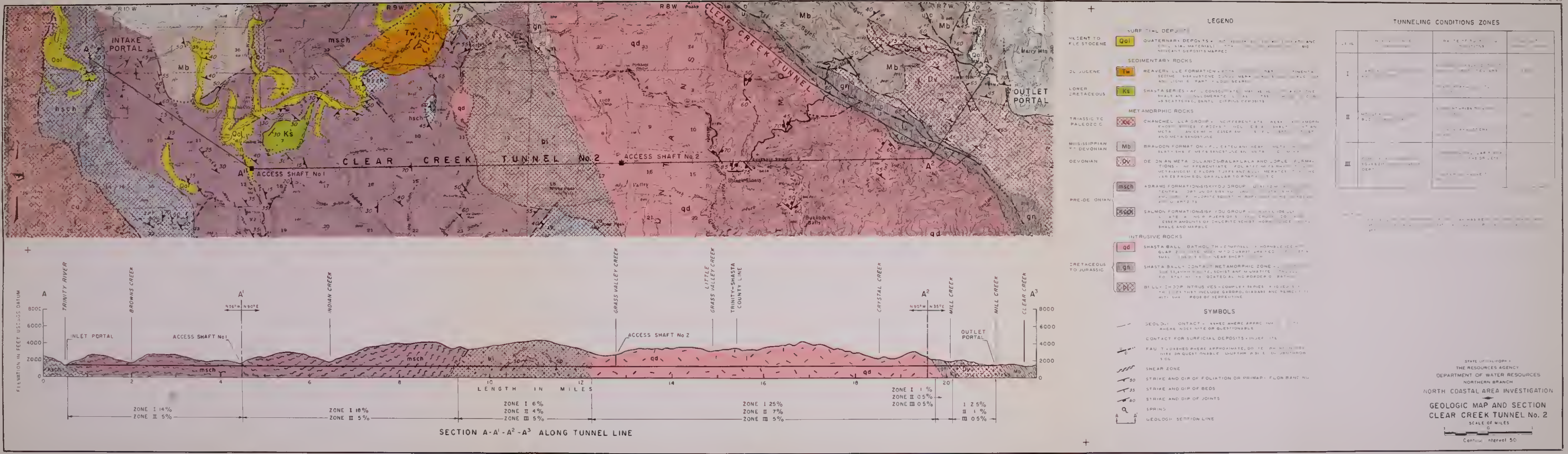


PLATE 26
INTAKE PORTAL
OUTLET PORTAL
CLEAR CREEK TUNNEL No. 2
ACCESS SHAFT No 1
ACCESS SHAFT No 2
CLEAR CREEK TUNNEL
LEGEND
SEDIMENTARY ROCKS
METAMORPHIC ROCKS
INTRUSIVE ROCKS
SYMBOLS
TUNNELING CONDITIONS ZONES
TRINITY RIVER
BROWNS CREEK
INDIAN CREEK
GRASS VALLEY CREEK
LITTLE GRASS VALLEY CREEK
TRINITY-SHASTA COUNTY LINE
CRYSTAL CREEK
MILL CREEK
CLEAR CREEK
INLET PORTAL
LENGTH IN MILES
ELEVATION IN FEET USGS DATUM
SECTION A-A'-A²-A³ ALONG TUNNEL LINE
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTION
CLEAR CREEK TUNNEL No. 2
SCALE OF MILES
Contour interval 50

LEGEND

QUATERNARY DEPOSITS – UNCONSOLIDATED STREAM, TERRACE AND COLLUVIAL MATERIALS, LOCALLY AURIFEROUS, ONLY SIGNIFICANT DEPOSITS MAPPED.

WEAVERVILLE FORMATION – PARTLY CONSOLIDATED CONTINENTAL SEDIMENTS TO INCLUDE SANDSTONE, CONGLOMERATE, SHALE, MUDSTONE, TUFF AND LIGNITE.

SHASTA SERIES – PASKENTA AND HORSETOWN FORMATIONS – WELL CONSOLIDATED MARINE BEDS OF SANDSTONE, SHALE AND CONGLOMERATE. LOCALLY FOSSILIFEROUS. OCCURS AS SCATTERED, GENTLY DIPPING DEPOSITS IN THE KLAMATH MOUNTAINS. COMPRISES A THICK SEDIMENTARY SECTION IN SOUTHERN PART OF AREA

SHASTA BALLY BATHOLITH – HORNBLENDE QUARTZ DIORITE, MEDIUM TO COARSE GRAINED. FOLIATED CONTACT METAMORPHIC ZONE ALONG BORDERS OF BATHOLITH COMPOSED OF GNEISS, SCHIST, AMPHIBOLITE AND MIGMATITE INCLUDES SMALL IGNEOUS BODIES ALONG BROWNS CREEK.

BULLY CHOOP ULTRABASIC BODY – A COMPLEX SERIES OF IGNEOUS INTRUSIVES THAT INCLUDE PERIDOTITE, DIABASE, GABBRO, DIORITE AND SERPENTINE.CONTAINS PODS OF CHROMITE.

CHANCHELULLA GROUP – UNDIFFERENTIATED, WEAKLY METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS TO INCLUDE SLATE, META-VOLCANICS AND CHERT WITH LESSER AMOUNTS OF LIMESTONE, SCHIST AND META-SANDSTONE.

BRAGDON FORMATION – COMPRISED OF MILDLY METAMORPHOSED SLATY SHALE, SANDSTONE AND CONGLOMERATE.

SISKIYOU GROUP–ABRAMS AND SALMON FORMATIONS – OLDEST AND MOST HIGHLY METAMORPHOSED ROCKS OF THE KLAMATH MOUNTAINS.

ABRAMS QUARTZ MICA SCHIST – LOCATED IN CENTRAL PORTION OF METAMORPHIC BELT. CONTAINS MINOR AMOUNTS OF CHLORITE AND HORNBLENDE SCHIST, MARBLE AND QUARTZITE.

SALMON HORNBLENDE SCHIST – LOCATED ALONG BORDERS OF METAMORPHIC BELT. CONTAINS LESSOR AMOUNTS OF CHLORITE SCHIST, HORNBLENDE GNEISS, SHALE AND MARBLE.

SYMBOLS

-DASHED WHERE APPROXIMATELY LOCATED

-INFERRED OR QUESTIONABLE

FOR SURFICIAL DEPOSITS–INDEFINITE

ASHED WHERE APPROXIMATELY LOCATED.
PTHROW SIDE, D–DOWNTHROW SIDE.

IDEFINITE CONTACT ZONE

E FAULT

SHEAR ZONE

35 STRIKE AND DIP OF BEDS

70 STRIKE AND DIP OF FOLIATION

VERTICAL FOLIATION OR CLEAVAGE

SPRING

A A' GEOLOGIC SECTION LINE

MPILED

SURVEY

. 2.

NELING

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

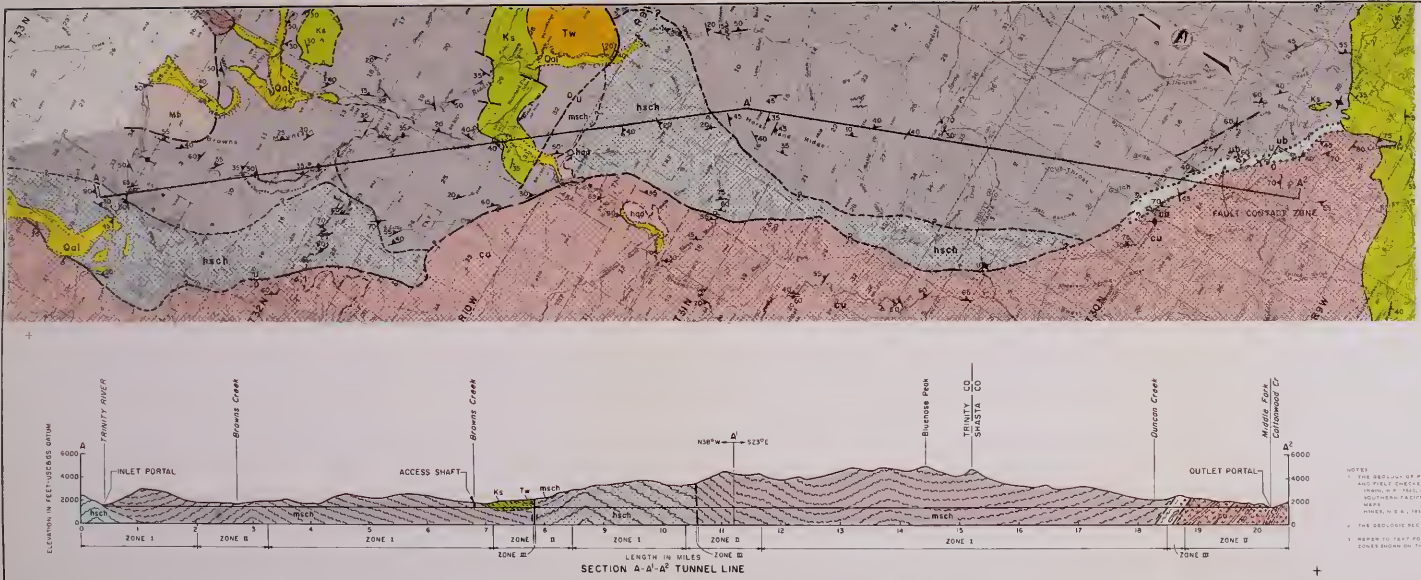
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION COTTONWOOD CREEK TUNNEL

SCALE OF MILES

1 0 1

Contour Intervol 100'



LEGEND

QUATERNARY	RECENT TO PLEISTOCENE	Qal	QUATERNARY DEPOSITS – UNCONSOLIDATED STREAM TERRACE AND COLLUVIAL MATERIALS LOCALLY AURIFEROUS, ONLY SIGNIFICANT DEPOSITS MAPPED
TERTIARY	OLIGOCENE	Tw	WEAVERVILLE FORMATION – PARTLY CONSOLIDATED CONTINENTAL SEDIMENTS TO INCLUDE SANDSTONE, CONGLOMERATE, SHALE, MUDSTONE, TUFF AND LIGNITE
MESOZOIC	CRETACEOUS	Ks	SHASTA SERIES – PASKENTA AND HORSETOWN FORMATIONS – WELL CONSOLIDATED MARINE BEDS OF SANDSTONE, SHALE AND CONGLOMERATE LOCALLY FOSSILIFEROUS. OCCURS AS SCATTERED GENTLY DIPPING DEPOSITS IN THE KLAMATH MOUNTAINS. COMPRISES A THICK SEDIMENTARY SECTION IN SOUTHERN PART OF AREA
	CRETACEOUS TO JURASSIC	hqd	SHASTA BALLY BATHOLITH – HORNBLENDE QUARTZ DIORITE, MEDIUM TO COARSE GRAINED, FOLIATED CONTACT METAMORPHIC ZONE ALONG BORDERS OF BATHOLITH COMPOSED OF GNEISS, SCHIST, AMPHIBOLITE AND MIGMATITE INCLUDES SMALL IGNEOUS BODIES ALONG BROWNS CREEK
		ub	BULLY CHOOP ULTRABASIC BODY – A COMPLEX SERIES OF IGNEOUS INTRUSIVES THAT INCLUDE PERIDOTITE, DIABASE, GABBRO, DIORITE AND SERPENTINE, CONTAINS PODS OF CHROMITE
	TRIASSIC TO PALEOZOIC	cu	CHANCHELULLA GROUP – UNDIFFERENTIATED, WEAKLY METAMORPHOSED SEDIMENTARY AND VOLCANIC ROCKS TO INCLUDE SLATE, METAVOLCANICS AND CHERT WITH LESSER AMOUNTS OF LIMESTONE, SCHIST AND META-SANDSTONE
PALEOZOIC	DEVONIAN TO MISSISSIPPIAN	Mb	BRAGDON FORMATION – COMPRISED OF MILDLY METAMORPHOSED SLATE, SHALE, SANDSTONE AND CONGLOMERATE
	PRE-DEVONIAN		SISKIYOU GROUP – ABRAMS AND SALMON FORMATIONS – OLDEST AND MOST HIGHLY METAMORPHOSED ROCKS OF THE KLAMATH MOUNTAINS
		msch	ABRAMS QUARTZ MICA SCHIST – LOCATED IN CENTRAL PORTION OF METAMORPHIC BELT. CONTAINS MINOR AMOUNTS OF CHLORITE AND HORNBLENDE SCHIST, MARBLE AND QUARTZITE.
		hsch	SALMON HORNBLENDE SCHIST – LOCATED ALONG BORDERS OF METAMORPHIC BELT. CONTAINS LESSER AMOUNTS OF CHLORITE SCHIST, HORNBLENDE GNEISS, SHALE AND MARBLE

SYMBOLS

CONTACT-DASHED WHERE APPROXIMATELY LOCATED

CONTACT INFERRED OR QUESTIONABLE

CONTACT ON SURFICIAL DEPOSITS-INDEFINITE

FAULT-DASHED WHERE APPROXIMATELY LOCATED U-UPTHROWN SIDE, D-DOWNTHROWN SIDE

FAULT-INDEFINITE CONTACT ZONE

PROBABLE FAULT

SHEAR ZONE

STRIKE AND DIP OF BEDS

STRIKE AND DIP OF FOLIATION

VERTICAL FOLIATION

SPRING

GEOLOGIC SECTION LINE

NOTES

1. THE GEOLOGY OF PORTIONS OF THIS MAP HAVE BEEN COMPILED AND FIELD CHECKED FROM THE FOLLOWING SOURCES:
   IRWIN, W.P., 1950, CALIF. DIV. OF MINES, BULLETIN 179
   SOUTHERN PACIFIC RAILROAD CO., 1956-57, MINERAL SURVEY MAPS
   HINES, N.E.A., 1955, CALIF. DIV. OF MINES, V.28, NO. 1
2. THE GEOLOGIC SECTION IS PARTIALLY DIAGRAMMATIC
3. REFER TO TEXT FOR A DETAILED DESCRIPTION OF TUNNELING ZONES SHOWN ON THE GEOLOGIC SECTION

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION COTTONWOOD CREEK TUNNEL

SCALE OF MILES

Contour Interval 100'

LEGEND

RECENT	Qal	STREAM ALLUVIUM
TERTIARY PLIOCENE	Tt	TEHAMA FORMATION FLOOD PLAIN SEDIMENTS
	Ttn	NOMLAKI TUFF
MESOZOIC CRETACEOUS BEDROCK SERIES	M	MUDSTONE AND SHALE WITH MORE THAN 25% SANDSTONE
	Ms	MUDSTONE AND SHALE WITH OCCASIONAL SANDSTONE INTERBEDS
	S	SANDSTONE WITH OCCASIONAL MUDSTONE INTERBEDS
	C	CONGLOMERATE

SYMBOLS

45 STRIKE AND DIP OF BEDDING

FAULT

SHEAR ZONE

APPROXIMATE GEOLOGIC CONTACT

PROPOSED DAMSITES

OPEN CUT CONVEYANCE CHANNEL

NOTE: ALTERNATE DEVELOPMENT PROJECTS ARE DASHED.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

AREAL GEOLOGY
WESTSIDE FEEDER SYSTEM
FIDDLERS RESERVOIR TO TRUEBLOOD RESERVOIR

SCALE OF MILES

0 1/2 1

Contour Interval 50'

LEGEND

RECENT	Qal	STREAM ALLUVIUM
TERTIARY PLIOCENE	Tt	TEHAMA FORMATION FLOOD PLAIN SEDIMENTS
	Ttn	NOMLAKI TUFF
MESOZOIC CRETACEOUS BEDROCK SERIES	M	MUDSTONE AND SHALE WITH MORE THAN 25% SANDSTONE
	Ms	MUDSTONE AND SHALE WITH OCCASIONAL SANDSTONE INTERBEDS
	S	SANDSTONE WITH OCCASIONAL MUDSTONE INTERBEDS
	C	CONGLOMERATE

SYMBOLS

- 45 STRIKE AND DIP OF BEDDING
- FAULT
- SHEAR ZONE
- APPROXIMATE GEOLOGIC CONTACT
- PROPOSED DAMSITES
- OPEN CUT CONVEYANCE CHANNEL

NOTE: ALTERNATE DEVELOPMENT PROJECTS ARE DASHED.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

AREAL GEOLOGY
WESTSIDE FEEDER SYSTEM
FIDDLERS RESERVOIR TO TRUEBLOOD RESERVOIR

SCALE OF MILES
0 1/2 1

Contour Interval 50'

LEGEND

RECENT	Qal	STREAM ALLUVIUM
TERTIARY PLIOCENE	Tt	TEHAMA FORMATION FLOOD PLAIN SEDIMENTS
	Ttn	NOMLAKI TUFF
MESOZOIC CRETACEOUS BEDROCK SERIES	M	MUDSTONE AND SHALE WITH MORE THAN 25% SANDSTONE
	Ms	MUDSTONE AND SHALE WITH OCCASIONAL SANDSTONE INTERBEDS
	S	SANDSTONE WITH OCCASIONAL MUDSTONE INTERBEDS
	C	CONGLOMERATE

SYMBOLS

- 50 STRIKE AND DIP OF BEDDING
- FAULT
- SHEAR ZONE
- APPROXIMATE GEOLOGIC CONTACT
- PROPOSED DAMSITES
- OPEN CUT CONVEYANCE CHANNEL

NOTE: ALTERNATE DEVELOPMENT PROJECTS ARE OASHED.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

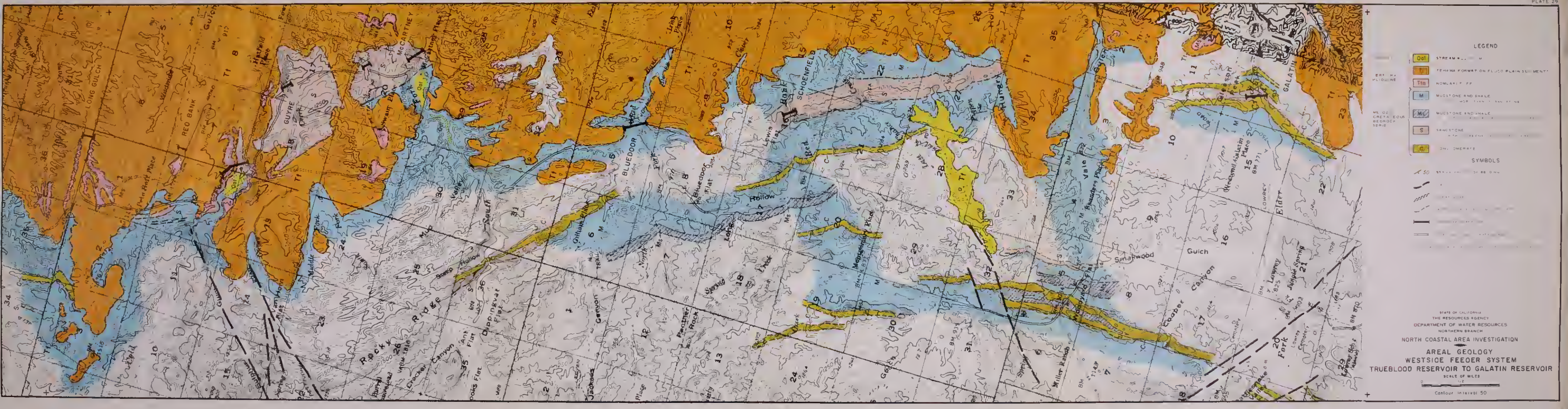
NORTH COASTAL AREA INVESTIGATION

AREAL GEOLOGY
WESTSIDE FEEDER SYSTEM
TRUEBLOOD RESERVOIR TO GALATIN RESERVOIR

SCALE OF MILES

0 1/2 1

Contour Interval 50'


LEGEND
Qal
Ti
Tin
M
MUDSTONE AND SHALE
Ms
S
C
SYMBOLS
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
AREAL GEOLOGY
WESTSIDE FEEDER SYSTEM
TRUEBLOOD RESERVOIR TO GALATIN RESERVOIR
SCALE OF MILES
Contour interval 50
LONG GULCH
RED BANK
GUYRE
MCCARTNEY
BLUEDOOR
Bluedoor Flat
SCHOENFIELD
Lone Hollow
Rocky Ridge
Gilham
Smallwood Gulch
Cooper Canyon
GALATIN
Panther Rock
Jacksons Canyon
Miller Ranch
Elder

LEGEND

RECENT	Qal	STREAM ALLUVIUM
TERTIARY PLIOCENE	Tt	TEHAMA FORMATION FLOOD PLAIN SEDIMENTS
	Ttn	NOMLAKI TUFF
MESOZOIC CRETACEOUS BEDROCK SERIES	M	MUDSTONE AND SHALE WITH MORE THAN 25% SANDSTONE
	Ms	MUDSTONE AND SHALE WITH OCCASIONAL SANDSTONE INTERBEDS
	S	SANDSTONE WITH OCCASIONAL MUDSTONE INTERBEDS
	C	CONGLOMERATE

SYMBOLS

- 45 STRIKE AND DIP OF BEDDING
- FAULT
- SHEAR ZONE
- APPROXIMATE GEOLOGIC CONTACT
- PROPOSED DAMSITES
- OPEN CUT CONVEYANCE CHANNEL

NOTE: ALTERNATE DEVELOPMENT PROJECTS ARE DASHED.

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DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

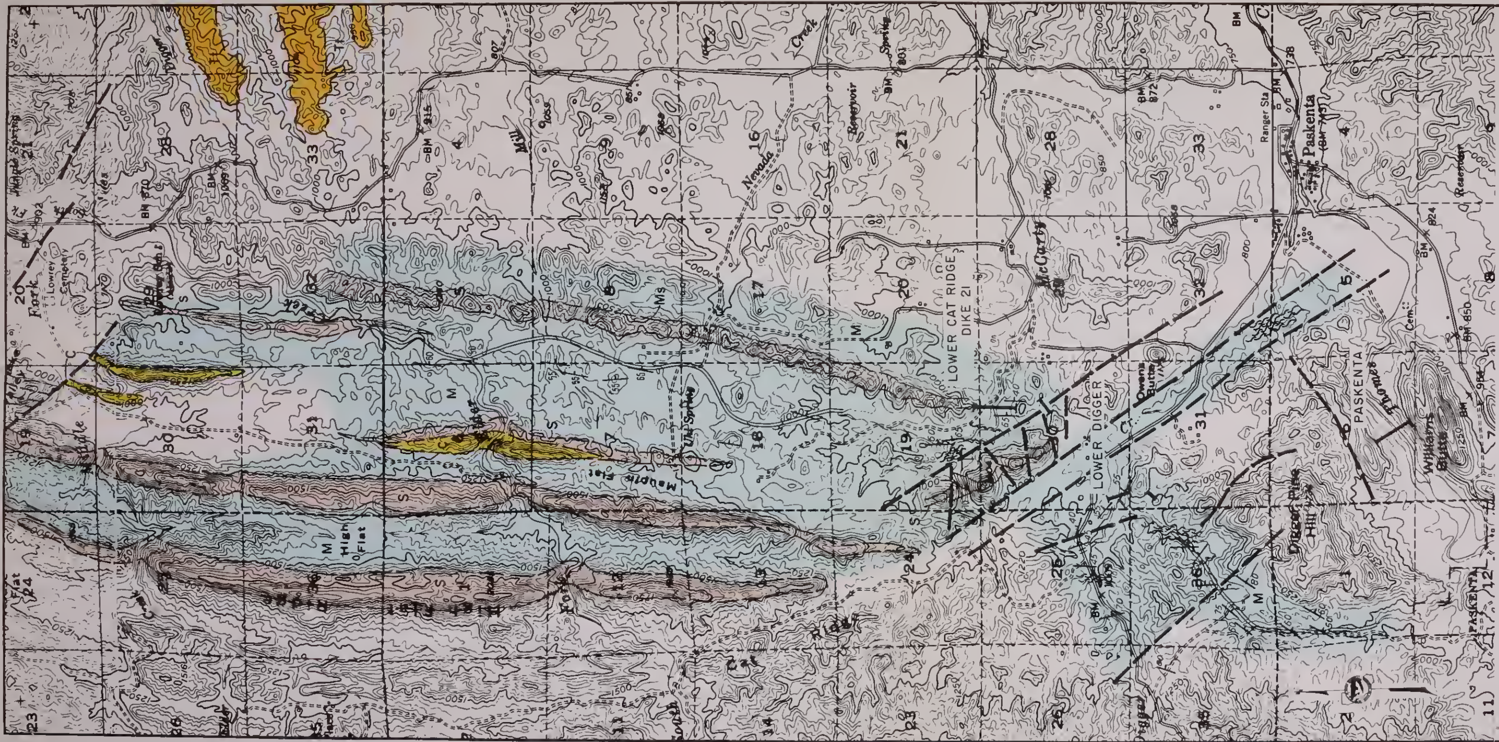
NORTH COASTAL AREA INVESTIGATION

AREAL GEOLOGY
WESTSIDE FEEDER SYSTEM
GALATIN RESERVOIR TO PASKENTA RESERVOIR

SCALE OF MILES

0 1/2

Contour Interval 50'



LEGEND

RECENT	Qal	STREAM ALLUVIUM
TERTIARY PLIOCENE	Tt	TEHAMA FORMATION FLOOD PLAIN SEDIMENTS
	Ttn	NOMLAKI TUFF
MESOZOIC CRETACEOUS BEDROCK SERIES	M	MUDSTONE AND SHALE WITH MORE THAN 25% SANDSTONE
	Ms	MUDSTONE AND SHALE WITH OCCASIONAL SANDSTONE INTERBEDS
	S	SANDSTONE WITH OCCASIONAL MUDSTONE INTERBEDS
	C	CONGLOMERATE

SYMBOLS

- 45 STRIKE AND DIP OF BEDDING
- FAULT
- SHEAR ZONE
- APPROXIMATE GEOLOGIC CONTACT
- PROPOSED DAMSITES
- OPEN CUT CONVEYANCE CHANNEL

NOTE: ALTERNATE DEVELOPMENT PROJECTS ARE DASHED

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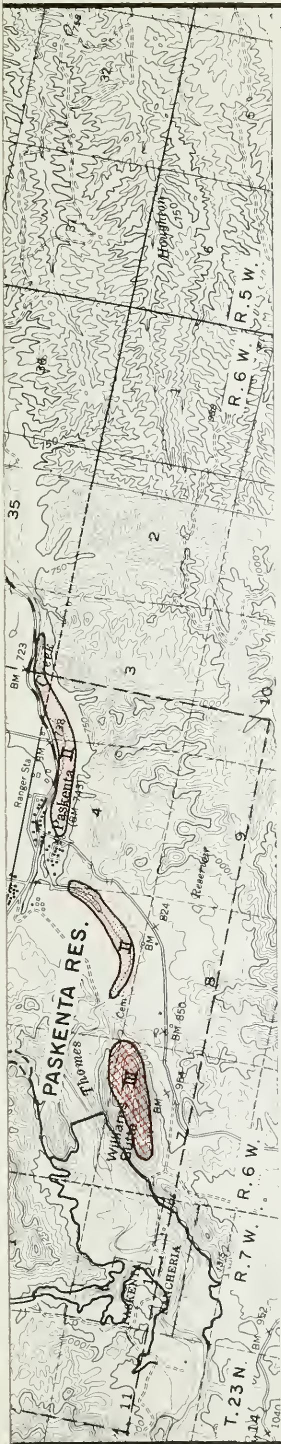
AREAL GEOLOGY
WESTSIDE FEEDER SYSTEM
GALATIN RESERVOIR TO PASKENTA RESERVOIR

SCALE OF MILES

0 1/2

Contour Interval 50'



LEGEND

I — IMPERVIOUS BORROW AREA

II — SOURCE OF PERVIOUS MATERIAL SUITABLE FOR FILTERS AND DRAINS

III — ROCKFILL AND RIPRAP

PROPOSED RESERVOIRS

OPEN CUT CONVEYANCE CHANNEL

NOTE: ALTERNATE DEVELOPMENT PROJECTS ARE DASHED.

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NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS WESTSIDE FEEDER SYSTEM

SCALE OF MILES

0 1 2

Contour Intervol 50'

R 8 W
R 7 W
R 7 W
R 6 W
M.D.B.& M.
TEHAMA
SHASTA
SHASTA CO.
TEHAMA CO.
T.29 N.
T.28 N.
T.27 N.
T.26 N.
FIDDLERS RES.
PLATE 28
UPPER PENTACOLA RES.
LOWER PENTACOLA RES.
LITTLE PENTACOLA RES.
MEADOW GULCH RES.
BIG CUT
SAUNDERS RES.
PLATE 29
TRUEBLOOD RES. GROUP
UPPER LONG GULCH RES.
LONG GULCH RES.
RED BANK RES.
COLD FORK RES.
GUYRE RES.
McCARTNEY RES.
BLUEDOOR RES.
SCHOENFIELD RES.

LEGEND

I	IMPERVIOUS BORROW AREA
II	SOURCE OF PERVIOUS MATERIAL SUITABLE FOR FILTERS AND DRAINS
III	ROCKFILL AND RIPRAP
	PROPOSED RESERVOIRS
	OPEN CUT CONVEYANCE CHANNEL

NOTE: ALTERNATE DEVELOPMENT PROJECTS ARE DASHED

STATE OF CALIFORNIA
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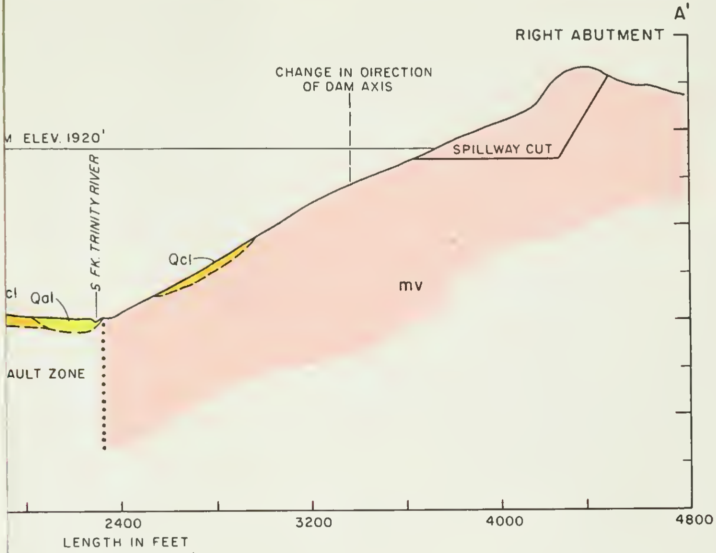
NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
WESTSIDE FEEDER SYSTEM

SCALE OF MILES

0 1 2

Contour Interval 50'



SECTION A-A'

LEGEND

D AND GRAVEL DEPOSITS IN THE RIVER CHANNEL WITH OCCASIONAL SMALL LENSES OF

PEWASH, RESIDUAL SOIL, LANDSLIDE DEBRIS, TALUS AND MINOR TERRACES NEAR THE
THE MAP ARE UNDERLAIN BY DEEP, NEARLY CONTINUOUS COLLUVIAL DEPOSITS. THE
A IS MANTLED BY RELATIVELY SHALLOW DISCONTINUOUS OVERBURDEN WHICH IS NOT

ED MODERATELY METAMORPHOSED PREDOMINANTLY METASEDIMENTARY ROCK. ROCK
METAVOLCANIC ROCK, HORNFELS, IGNEOUS DIKES, LIMESTONE, AND VEINS OF QUARTZ.
PEAR TO BE DISCONTINUOUS AND THE MAP UNIT IS EXTREMELY COMPLEX STRUCTUR-
IT CROPS OUT, THE REMAINDER OF THE AREA IS COVERED BY OVERBURDEN.

LOCALLY GRADING INTO PHYLLITE. THE ROCK IS GENERALLY BLACK, FISSILE, AND

ES.

EY – GREEN GENERALLY VERY FINE GRAINED META-ANDESITE. THE ROCK IS HARD AND
SH, PORTIONS ARE FOLIATED AND LOCALLY SHEARED. THE UNIT INCLUDES LENSES
INTRUSIVE DIKES.
T CROPS OUT: THE REMAINDER IS COVERED BY SHALLOW OVERBURDEN.

TIONS OR LENSES OF GABBRO AND SERPENTINE. THE ROCK IS GENERALLY VERY

ALTERED AND FRACTURED ULTRABASIC INTRUSIVE ROCK.

SYMBOLS

CONCEALED (OVERBURDEN CONTACTS ARE INDEFINITE).

ELY LOCATED, DOTTED WHERE CONCEALED OR INFERRED.

ABLE OR DISTURBED ATTITUDES ARE DASHED.

PROXIMATE

STATE OF CALIFORNIA
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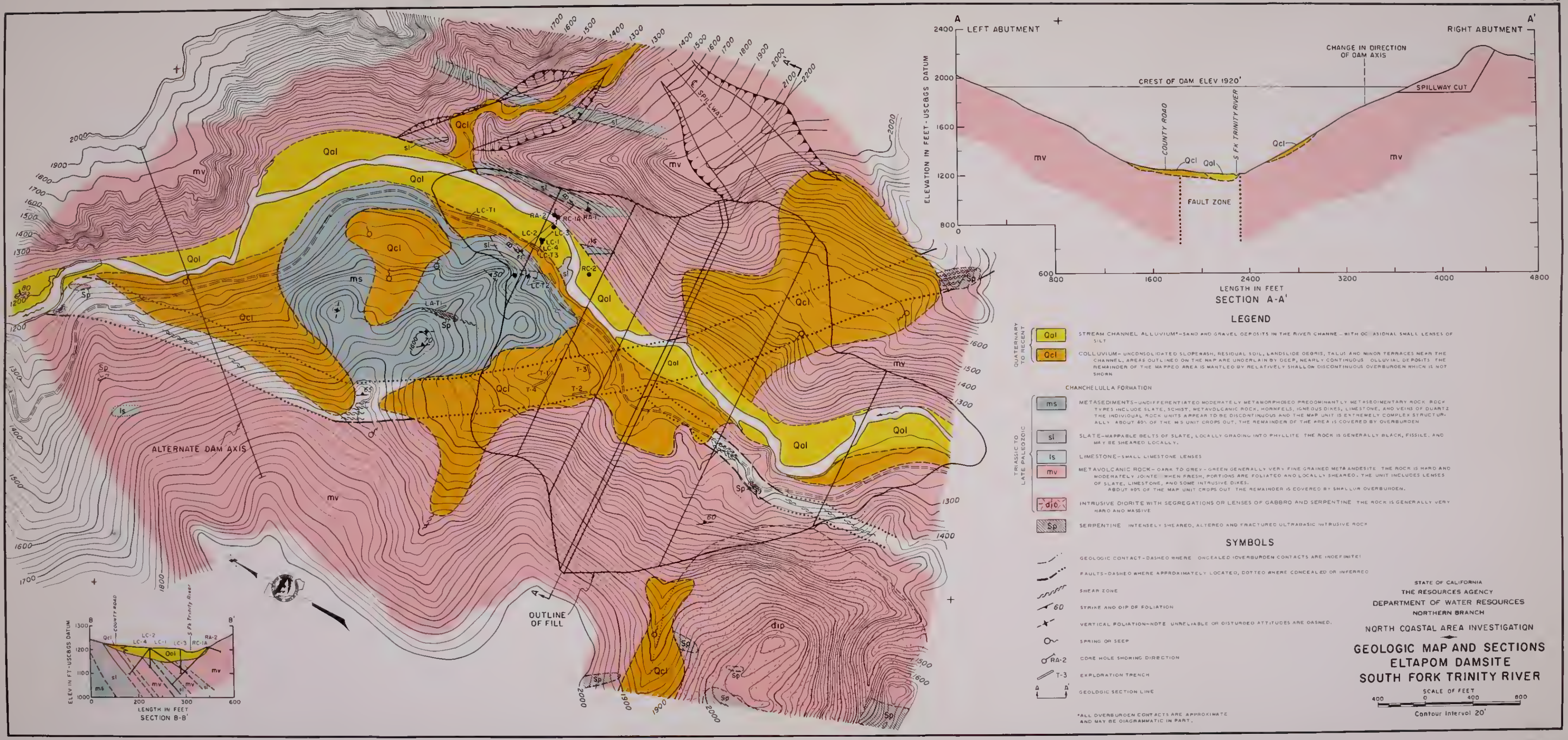
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS
ELTAPOM DAMSITE
SOUTH FORK TRINITY RIVER

SCALE OF FEET
400 0 400 800

Contour Interval 20'


A
LEFT ABUTMENT
A'
RIGHT ABUTMENT
CHANGE IN DIRECTION OF DAM AXIS
CREST OF DAM ELEV 1920'
SPILLWAY CUT
COUNTY ROAD
S FK TRINITY RIVER
FAULT ZONE
ELEVATION IN FEET - USCBGS DATUM
LENGTH IN FEET
SECTION A-A'
LEGEND
QUATERNARY TO RECENT
Qal STREAM CHANNEL ALLUVIUM* - SAND AND GRAVEL DEPOSITS IN THE RIVER CHANNEL WITH OCCASIONAL SMALL LENSES OF SILT
Qcl COLLUVIUM - UNCONSOLIDATED SLOPEWASH, RESIDUAL SOIL, LANDSLIDE DEBRIS, TALUS AND MINOR TERRACES NEAR THE CHANNEL. AREAS OUTLINED ON THE MAP ARE UNDERLAIN BY DEEP, NEARLY CONTINUOUS COLLUVIAL DEPOSITS. THE REMAINDER OF THE MAPPED AREA IS MANTLED BY RELATIVELY SHALLOW DISCONTINUOUS OVERBURDEN WHICH IS NOT SHOWN
CHANCHELULLA FORMATION
TRIASSIC TO LATE PALEOZOIC
ms METASEDIMENTS - UNDIFFERENTIATED MODERATELY METAMORPHOSED PREDOMINANTLY METASEDIMENTARY ROCK. ROCK TYPES INCLUDE SLATE, SCHIST, METAVOLCANIC ROCK, HORNFELS, IGNEOUS DIKES, LIMESTONE, AND VEINS OF QUARTZ. THE INDIVIDUAL ROCK UNITS APPEAR TO BE DISCONTINUOUS AND THE MAP UNIT IS EXTREMELY COMPLEX STRUCTURALLY. ABOUT 40% OF THE MS UNIT CROPS OUT, THE REMAINDER OF THE AREA IS COVERED BY OVERBURDEN
sl SLATE - MAPPABLE BELTS OF SLATE, LOCALLY GRADING INTO PHYLLITE. THE ROCK IS GENERALLY BLACK, FISSILE, AND MAY BE SHEARED LOCALLY.
ls LIMESTONE - SMALL LIMESTONE LENSES
mv METAVOLCANIC ROCK - DARK TO GREY-GREEN GENERALLY VERY FINE GRAINED META ANDESITE. THE ROCK IS HARD AND MODERATELY JOINTED WHEN FRESH, PORTIONS ARE FOLIATED AND LOCALLY SHEARED. THE UNIT INCLUDES LENSES OF SLATE, LIMESTONE, AND SOME INTRUSIVE DIKES. ABOUT 80% OF THE MAP UNIT CROPS OUT. THE REMAINDER IS COVERED BY SHALLOW OVERBURDEN.
dio INTRUSIVE DIORITE WITH SEGREGATIONS OR LENSES OF GABBRO AND SERPENTINE. THE ROCK IS GENERALLY VERY HARD AND MASSIVE
Sp SERPENTINE INTENSELY SHEARED, ALTERED AND FRACTURED ULTRABASIC INTRUSIVE ROCK
SYMBOLS
GEOLOGIC CONTACT - DASHED WHERE CONCEALED (OVERBURDEN CONTACTS ARE INDEFINITE)
FAULTS - DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE CONCEALED OR INFERRED
SHEAR ZONE
60 STRIKE AND DIP OF FOLIATION
VERTICAL FOLIATION - NOTE UNRELIABLE OR DISTURBED ATTITUDES ARE DASHED.
SPRING OR SEEP
RA-2 CORE HOLE SHOWING DIRECTION
T-3 EXPLORATION TRENCH
A A' GEOLOGIC SECTION LINE
*ALL OVERBURDEN CONTACTS ARE APPROXIMATE AND MAY BE DIAGRAMMATIC IN PART.
STATE OF CALIFORNIA
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GEOLOGIC MAP AND SECTIONS
ELTAPOM DAMSITE
SOUTH FORK TRINITY RIVER
SCALE OF FEET
Contour Interval 20'
SPILLWAY
ALTERNATE DAM AXIS
OUTLINE OF FILL
ELEV IN FT - USCBGS DATUM
LENGTH IN FEET
SECTION B-B'

PTION	ASSUMED AVERAGE DEPTH IN YARDS	QUANTITY YDS.³ (BANK MEASURES)
AVERVILLE AKLY CON- AYEY GRAVEL, ND SANDS.	16	9,500,000
ME AS I-1	2	1,000,000
ME AS I-1)	20	17,000,000
AVERVILLE ALE, SILTY YEY GRAVEL. SELECTIVE	NOT ESTIMATED	PROBABLY MORE THAN 20 MILLION YDS.³ OF USABLE MATERIAL.
AVERVILLE ME AS I-1)	NOT ESTIMATED HIGHLY VARIABLE	PROBABLY 2-3 MILLION YDS.³
GGREGATE L ALLUVIUM AND.	10	9,700,000
GGREGATE BUT ER GRAINED	10	12,600,000
SLOPE- E AND	5	7,000,000
)	5	12,000,000
D TERRACE	2	1,000,000
ENSTONE, F SHALE- ERPENTINE	NOT ESTIMATED	SUFFICIENT QUANTITY OF ROCK FOR THE PROPOSED DAM CAN BE OBTAINED FROM EITHER Q-1 OR Q-2.

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RTH COASTAL AREA INVESTIGATION

ION OF CONSTRUCTION MATERIALS
ELTAPOM DAMSITE

SCALE OF FEET

2000 0 2000 4000

Contour Interval 50'

AREA	DESCRIPTION	ASSUMED AVERAGE DEPTH IN YARDS	QUANTITY YDS.^{3} (BANK MEASURES)
I-1	IMPERVIOUS-WEAVERVILLE FORMATION-WEAKLY CONSOLIDATED CLAYEY GRAVEL, CLAYEY SILT AND SANDS.	16	9,500,000
I-2	IMPERVIOUS (SAME AS I-1	2	1,000,000
I-3	IMPERVIOUS (SAME AS I-1)	20	17,000,000
I-4	IMPERVIOUS-WEAVERVILLE FORMATION-SHALE, SILTY SAND AND CLAYEY GRAVEL. WILL REQUIRE SELECTIVE EXCAVATION.	NOT ESTIMATED	PROBABLY MORE THAN 2 MILLION YDS.^{3} OF USABLE MATERIAL.
I-5	IMPERVIOUS-WEAVERVILLE FORMATION (SAME AS I-1)	NOT ESTIMATED HIGHLY VARIABLE	PROBABLY 2-3 MILLION YDS.^{3}
P-1	PERVIOUS OR AGGREGATE RIVER CHANNEL ALLUVIUM GRAVEL AND SAND.	10	9,700,000
P-2	PERVIOUS OR AGGREGATE SIMILAR TO P-1 BUT SOMEWHAT FINER GRAINED	10	12,600,000
S-1	SEMI-PERVIOUS-SLOPEWASH, TERRACE AND ALLUVIUM	5	7,000,000
S-2	SEMI-PERVIOUS (SIMILAR TO S-1)	5	12,000,000
S-3	SEMI-PERVIOUS SLOPEWASH AND TERRACE	2	1,000,000
Q-1 & Q-2	ROCKFILL-GREENSTONE, WITH LENSES OF SHALE-LIMESTONE & SERPENTINE	NOT ESTIMATED	SUFFICIENT QUANTITY OF ROCK FOR THE PROPOSED DAM CAN BE OBTAINED FROM EITHER Q-1 OR Q-2.

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NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
ELTAPOM DAMSITE

SCALE OF FEET
2000 0 2000 4000
Contour Interval 50'

LEGEND

WEAVERVILLE FORMATION

POORLY CONSOLIDATED SEDIMENTS. NOT ENCOUNTERED BY THE TUNNEL.

CHANCHELULLA GROUP

WEAKLY METAMORPHOSED DETRITAL SEDIMENTS. COMPOSED PREDOMINANTLY OF SLATE WITH MINOR AMOUNTS OF PHYLLITE AND SCHIST.

CHERT – INTERBEDDED WITH METASEDIMENTARY AND METAVOLCANIC ROCK UNITS. HARD, THINLY STRATIFIED TO MASSIVE, USUALLY FOUND IN DISCONTINUOUS LENSE SHAPED BODIES.

LIMESTONE – FOUND IN SMALL LENSES THROUGHOUT THE CHANCHELULLA GROUP.

METAVOLCANICS – MILDLY METAMORPHOSED EXTRUSIVE AND INTRUSIVE BASIC IGNEOUS ROCKS. THE ROCK IS HARD, MASSIVE AND MODERATELY JOINTED.

INTRUSIVE ROCKS

IRONSIDE MT. BATHOLITH – INTRUSIVE ROCK COMPOSED PREDOMINANTLY OF MEDIUM GRAINED DIORITE. NEAR THE NORTHERN BORDER. THE BATHOLITH CONTAINS NUMEROUS BASIC INCLUSIONS.

ULTRABASIC INTRUSIVES – SMALL BODIES OF ULTRA BASIC ROCK RANGING FROM GABBRO TO PYROXENITE MAPPED NEAR THE INLET PORTAL. LOCALLY THE ROCK IS INTENSIVELY SHEARED AND SERPENTINIZED.

SERPENTINE – INTENSELY SHEARED, FRACTURED AND ALTERED ULTRA BASIC INTRUSIVES. THE ROCK HAS USUALLY A CHARACTERISTIC GREEN COLOR AND IS OFTEN REDUCED BY DEFORMATION TO A CLAYEY GOUGE.

SYMBOLS

STRIKE AND DIP OF CLEAVAGE OR FOLIATION

VERTICAL FOLIATION OR CLEAVAGE

NOTE: UNRELIABLE ATTITUDES ARE DASHED.

CONTORTED ATTITUDE – INDICATES AVERAGE STRIKE AND DIP

SHEAR ZONE

FAULT–DASHED WHERE APPROXIMATELY LOCATED; DOTTED WHERE INFERRED.

GEOLOGIC CONTACT–DASHED WHERE APPROXIMATELY LOCATED; DOTTED WHERE INFERRED.

A'

GEOLOGIC SECTION LINE

ENT
ND

NCE

NEL-

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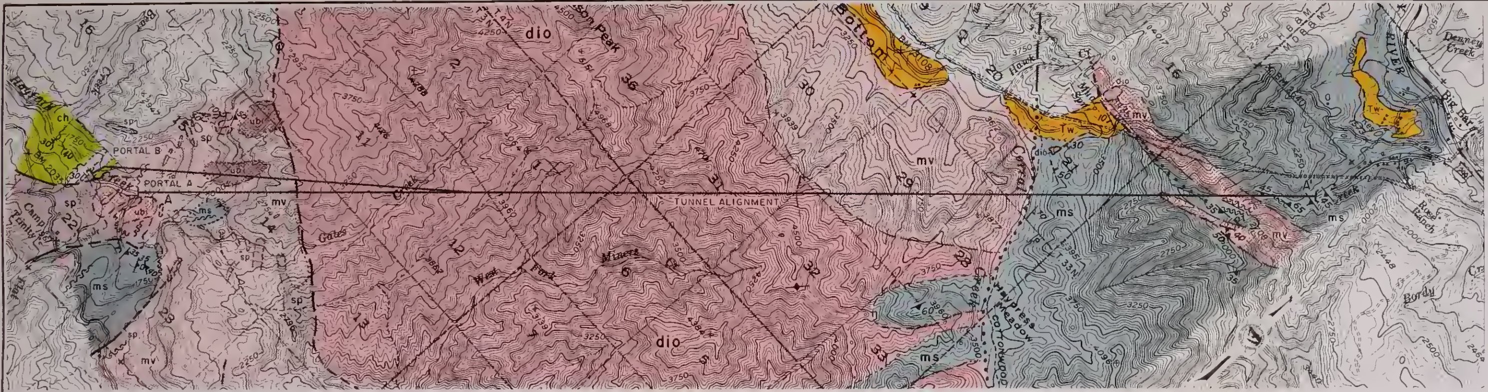
NORTH COASTAL AREA INVESTIGATION

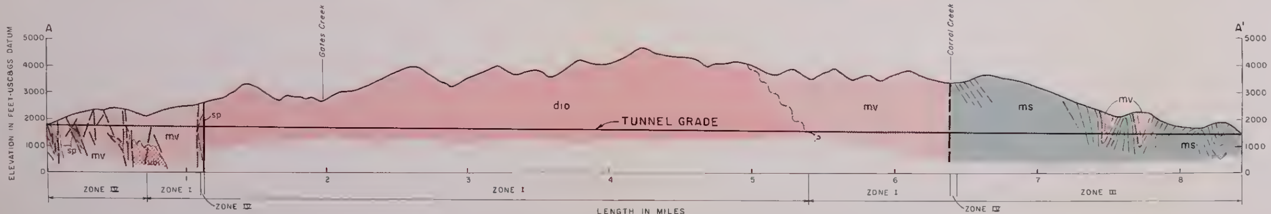
GEOLOGIC MAP AND SECTION ELTAPOM – BIG BAR TUNNEL

SCALE OF MILES

0 1 2

Contour Interval 50'





SECTION A-A'

LEGEND

WEAVERVILLE FORMATION

OLIGOCENE

Tw — POORLY CONSOLIDATED SEDIMENTS NOT EN[...]TERED BY THE TUNNEL.

CHANCHELULLA GROUP

TRIASSIC TO LATE PALEOZOIC

ms — WEAKLY METAMORPHOSED DETRITAL SEDIMENTS COMPOSED PREDOMINANTLY OF SLATE WITH MINOR AMOUNTS OF PHYLLITE AND SCHIST.

ch — CHERT — INTERBEDDED WITH METASEDIMENTARY AND METAVOLCANIC ROCK UNITS HARD, THINLY STRATIFIED TO MASSIVE, USUALLY FOUND IN DISCONTINUOUS LENSE SHAPED BODIES

ls — LIMESTONE — FOUND IN SMALL LENSES THROUGHOUT THE CHANCHELULLA GROUP

mv — METAVOLCANICS — MILDLY METAMORPHOSED EXTRUSIVE AND INTRUSIVE BASIC IGNEOUS ROCKS THE ROCK IS HARD, MASSIVE AND MODERATELY JOINTED

INTRUSIVE ROCKS

dio — IRONSIDE MT. BATHOLITH — INTRUSIVE ROCK COMPOSED PREDOMINANTLY OF MEDIUM GRAINED DIORITE NEAR THE NORTHERN BORDER THE BATHOLITH CONTAINS NUMEROUS BASIC INCLUSIONS

ubi — ULTRABASIC INTRUSIVES — SMALL BODIES OF ULTRA BASIC ROCK RANGING FROM GABBRO TO PYROXENITE MAPPED NEAR THE INLET PORTAL. LOCALLY THE ROCK IS INTENSIVELY SHEARED AND SERPENTINIZED

sp — SERPENTINE — INTENSELY SHEARED, FRACTURED AND ALTERED ULTRA BASIC INTRUSIVES. THE ROCK HAS USUALLY A CHARACTERISTIC GREEN COLOR AND IS OFTEN REDUCED BY DEFORMATION TO A CLAYEY GOUGE

SYMBOLS

70 — STRIKE AND DIP OF CLEAVAGE OR FOLIATION

VERTICAL FOLIATION OR CLEAVAGE

NOTE UNRELIABLE ATTITUDES ARE DASHED

50 — CONTORTED ATTITUDE — INDICATES AVERAGE STRIKE AND DIP

SHEAR ZONE

FAULT—DASHED WHERE APPROXIMATELY LOCATED, DOTTED WHERE INFERRED.

GEOLOGIC CONTACT—DASHED WHERE APPROXIMATELY LOCATED DOTTED WHERE INFERRED.

A A' — GEOLOGIC SECTION LINE

NOTES

1. THIS MAP SHOWS DISTRIBUTION OF BEDROCK UNITS RECENT SURFICIAL ACCUMULATION OF ALLUVIUM, SLOPEWASH AND LANDSLIDE DEBRIS ARE OMITTED.
2. THE GEOLOGIC STRUCTURE IS BASED ON RECONNAISSANCE WORK AND IS PARTIALLY DIAGRAMMATIC
3. REFER TO TEXT FOR A DETAILED DESCRIPTION OF TUNNELING CONDITIONS ZONES.

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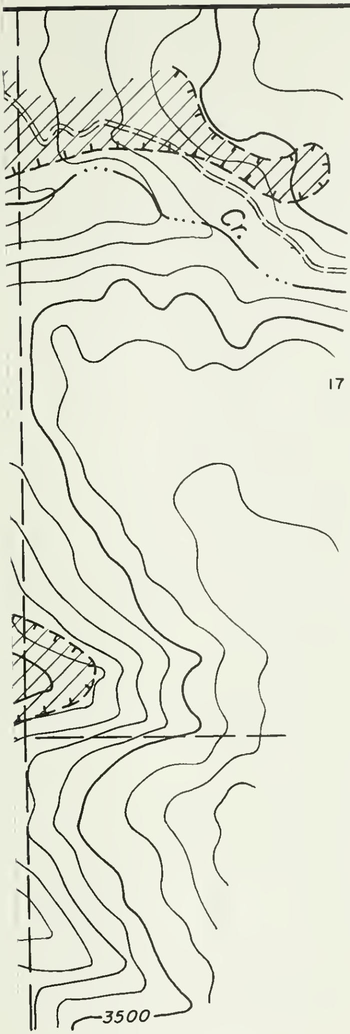
GEOLOGIC MAP AND SECTION ELTAPOM – BIG BAR TUNNEL

SCALE OF MILES

0 2

Contour Interval 50'



LEGEND

- Qls — LANDSLIDES
- Qt — TERRACE DEPOSIT
- BENCH SOILS

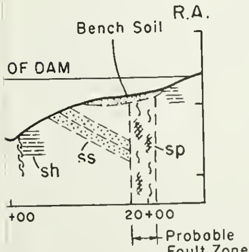
FRANCISCAN GROUP

- ss — SANDSTONE
- sh — SHALE
- gs — GREENSTONE
- sp — SERPENTINE

NOTE: ALL OTHER PORTIONS OF DAMSITE COVERED BY SLOPEWASH OR RESIDUAL SOIL OR LANDSLIDES.

SYMBOLS

- 60 — STRIKE AND DIP OF BEDS
- 10 — STRIKE AND DIP OF BEDDING, UNCERTAIN
- SHEAR ZONE
- GEOLOGIC CONTACT-DASHED WHERE APPROXIMATELY LOCATED.
- FAULT
- A A' — GEOLOGIC SECTION LINE



DAM SECTION

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THE RESOURCES AGENCY
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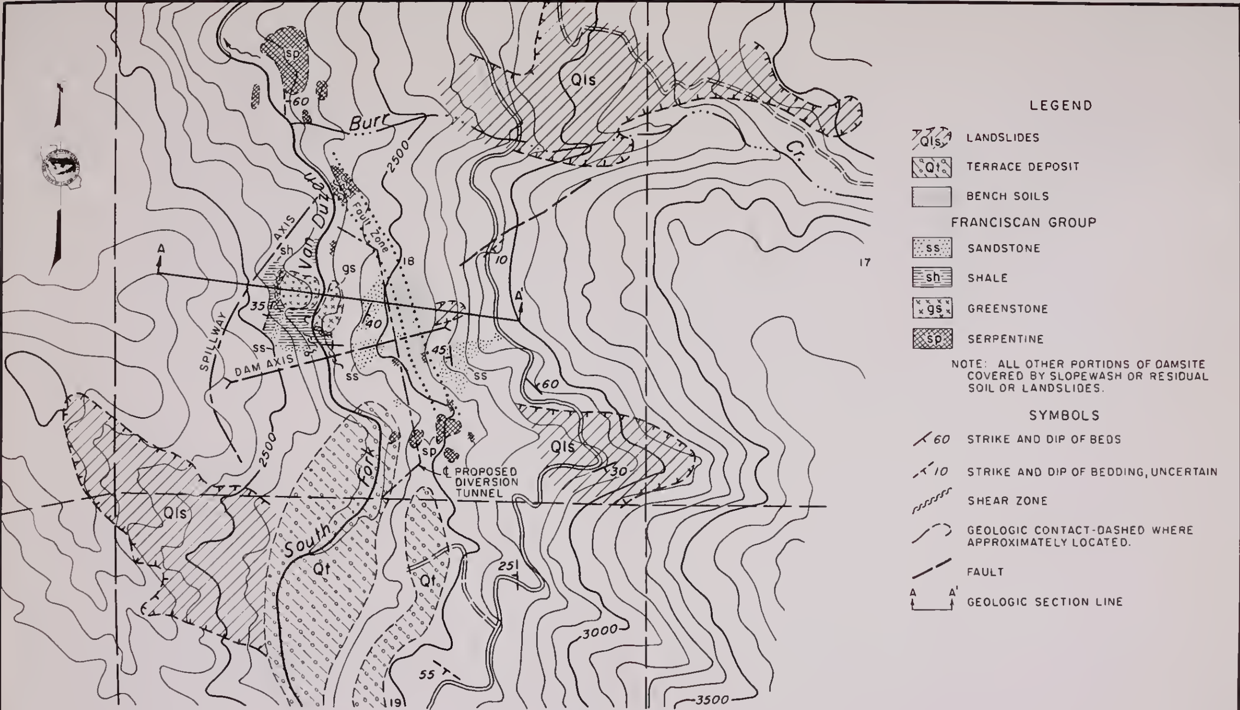
NORTHERN BRANCH

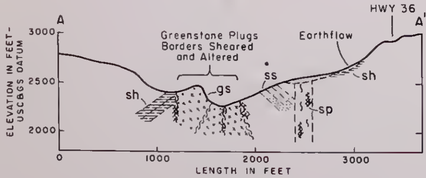
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS LARABEE VALLEY DAMSITE SOUTH FORK VAN DUZEN RIVER

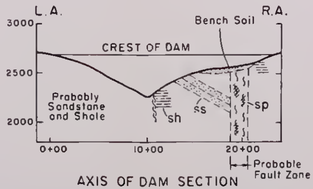
SCALE OF FEET
1000 0 1000

Contour Interval 100'





SECTION A-A'



AXIS OF DAM SECTION

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NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS LARABEE VALLEY DAMSITE SOUTH FORK VAN DUZEN RIVER

SCALE OF FEET

1000 0 1000

Contour Interval 100'

LEGEND

AN GROUP

FFERENTIATED FRANCISCAN - PREDOMINANTLY GRAYWACKE SANDSTONE WITH INTERBEDS OF SHALE. MINOR LENSES OF CONGLOMERATE, CHERT, GREENSTONE, GLAUCOPHANE SCHIST AND SERPENTINE.

T – THINLY BEDDED, HARD AND BRITTLE SILICEOUS ROCKS FOUND IN DISCONTINUOUS LENSES ASSOCIATED WITH GREENSTONE.

NSTONE – DENSE, HARD ALTERED BASIC VOLCANIC ROCK BOTH OF INTRUSIVE AND EXTRUSIVE ORIGIN. GREENSTONE IS FOUND THROUGHOUT THE TUNNEL AREA IN SMALL LENSE SHAPED BODIES AND APPEARS TO BE MOST ABUNDANT IN FAULT ZONES.

T – VARIOUS METAMORPHIC ROCKS FOUND IN SMALL MASSES IN THE FAULT ZONES. ROCK TYPES INCLUDE GLAUCOPHANE, ACTINOLITE AND GARNET SCHISTS.

ENTINE – INTENSELY ALTERED AND SHEARED ULTRABASIC ROCK FOUND IN SMALL LENSES IN SHEAR AND FAULT ZONES.

SYMBOLS

E AND DIP OF BEDDING

CAL BEDDING

ED OR UNRELIABLE ATTITUDE

R ZONE

T – DASHED WHERE APPROXIMATELY LOCATED

ROPS OF MAPPABLE ROCK UNITS

OF PROPOSED DAMSITE

OSED TUNNEL ALIGNMENT

G

HURDUS SPRING

DISTRIBUTION OF BEDROCK UNITS. RECENT SURFICIAL ACCUMULATIONS OF SH AND LANDSLIDE DEBRIS ARE OMITTED.

TURE SHOWN ON THE CROSS-SECTION IS BASED ON RECONNAISSANCE WORK AND ED AS PARTIALLY DIAGRAMMATIC.

FOR A DETAILED DESCRIPTION OF TUNNELING CONDITIONS ZONES.

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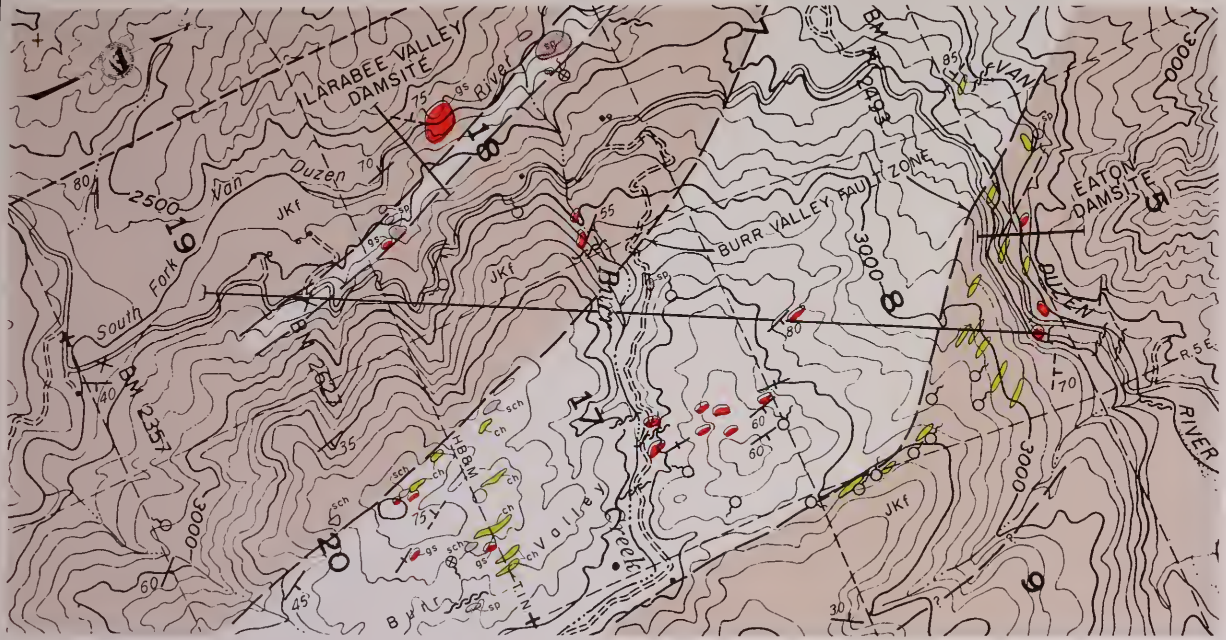
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION
LARABEE TUNNEL

SCALE OF FEET

1600 0 1600

Contour Interval 100'



LEGEND

UPPER JURASSIC TO LOWER CRETACEOUS

FRANCISCAN GROUP

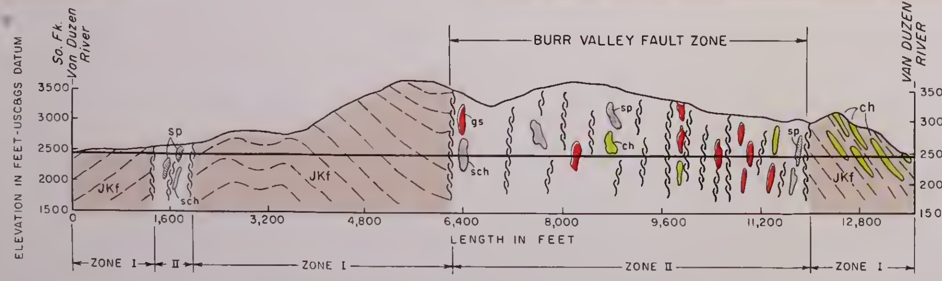
- **JKf** UNDIFFERENTIATED FRANCISCAN - PREDOMINANTLY GRAYWACKE SANDSTONE WITH INTERBEDS OF SHALE. MINOR LENSES OF CONGLOMERATE, CHERT, GREENSTONE, GLAUCOPHANE SCHIST AND SERPENTINE.
- **ch** CHERT - THINLY BEDDED, HARD AND BRITTLE SILICEOUS ROCKS FOUND IN DISCONTINUOUS LENSES ASSOCIATED WITH GREENSTONE.
- **gs** GREENSTONE - DENSE, HARD ALTERED BASIC VOLCANIC ROCK BOTH OF INTRUSIVE AND EXTRUSIVE ORIGIN. GREENSTONE IS FOUND THROUGHOUT THE TUNNEL AREA IN SMALL LENSE SHAPED BODIES AND APPEARS TO BE MOST ABUNDANT IN FAULT ZONES.
- **sch** SCHIST - VARIOUS METAMORPHIC ROCKS FOUND IN SMALL MASSES IN THE FAULT ZONES. ROCK TYPES INCLUDE GLAUCOPHANE, ACTINOLITE AND GARNET SCHISTS.
- **sp** SERPENTINE - INTENSELY ALTERED AND SHEARED ULTRABASIC ROCK FOUND IN SMALL LENSES IN SHEAR AND FAULT ZONES.

SYMBOLS

- 50 STRIKE AND DIP OF BEDDING
- VERTICAL BEDDING
- 70 SLUMPED OR UNRELIABLE ATTITUDE
- SHEAR ZONE
- ? FAULT - DASHED WHERE APPROXIMATELY LOCATED
- gs sp OUTCROPS OF MAPPABLE ROCK UNITS
- AXIS OF PROPOSED DAMSITE
- PROPOSED TUNNEL ALIGNMENT
- SPRING
- SULPHUROUS SPRING

NOTES:

1. THIS MAP SHOWS THE DISTRIBUTION OF BEDROCK UNITS. RECENT SURFICIAL ACCUMULATIONS OF ALLUVIUM, SLOPE WASH AND LANDSLIDE DEBRIS ARE OMITTED.
2. THE GEOLOGIC STRUCTURE SHOWN ON THE CROSS-SECTION IS BASED ON RECONNAISSANCE WORK AND SHOULD BE CONSIDERED AS PARTIALLY DIAGRAMMATIC.
3. REFER TO THE TEXT FOR A DETAILED DESCRIPTION OF TUNNELING CONDITIONS ZONES.



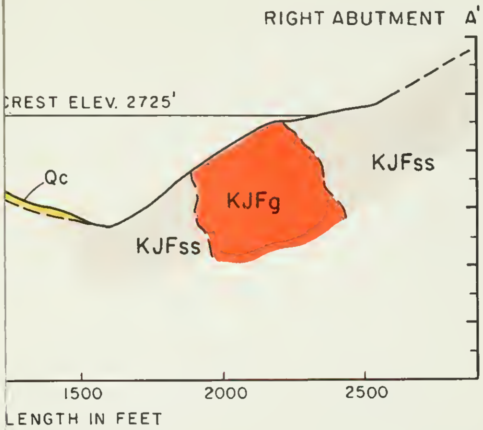
GEOLOGIC SECTION AND TUNNELING CONDITIONS ZONES

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION LARABEE TUNNEL

SCALE OF FEET
1600 0 1600
Contour Interval 100'



SECTION A-A'

LEGEND

IUM – SOIL, SLOPEWASH AND SHALLOW LANDSLIDE
ERALLY SHALLOW AND LOCALLY DISCONTINUOUS.

– DEEP ACCUMULATIONS OF SLOPEWASH AND
BRIS. AVERAGE DEPTH IS MORE THAN 15 FEET.
LIDE MOVEMENT IS INDICATED BY ARROWS.

SHALE INTERBEDS

BEDDED TO MASSIVE.

LTERED BASIC VOLCANIC ROCK.

CHIST AND ASSOCIATED METAMORPHIC ROCKS

SYMBOLS

T – DASHED WHERE APPROXIMATE, DOTTED
NITE OR INFERRED.

INCLINED STRATA.

ATION OR CLEAVAGE.

WHERE INFERRED OR CONCEALED.

LINE

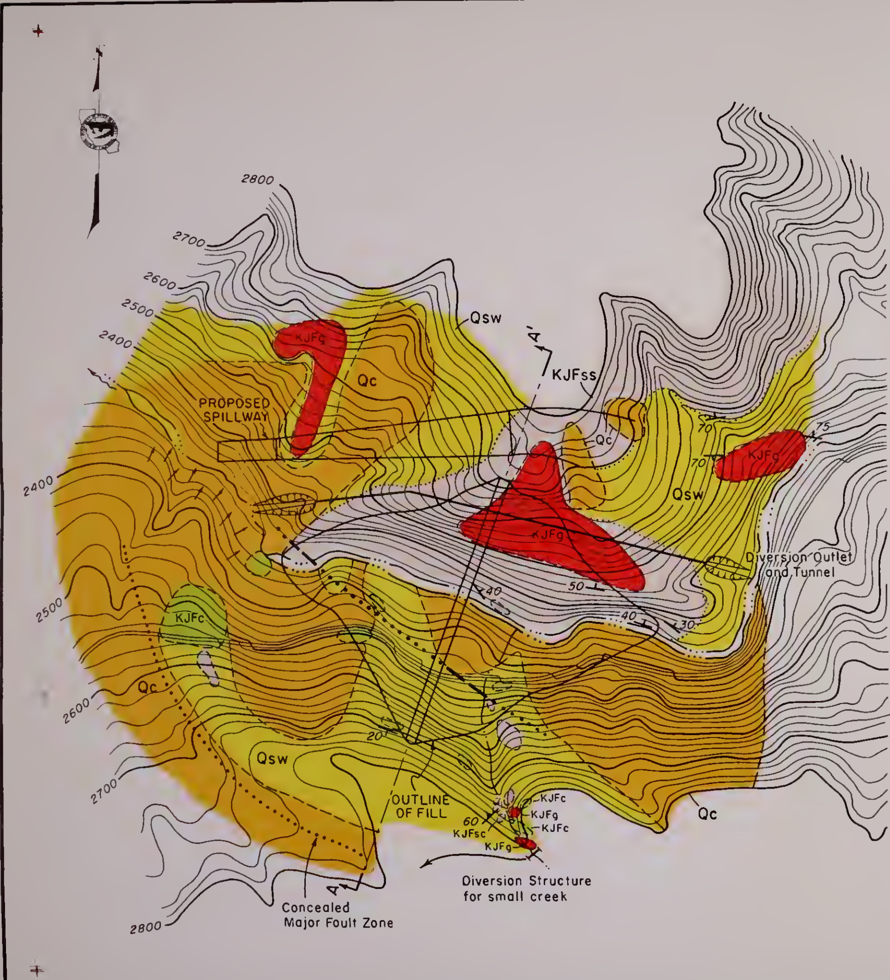
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

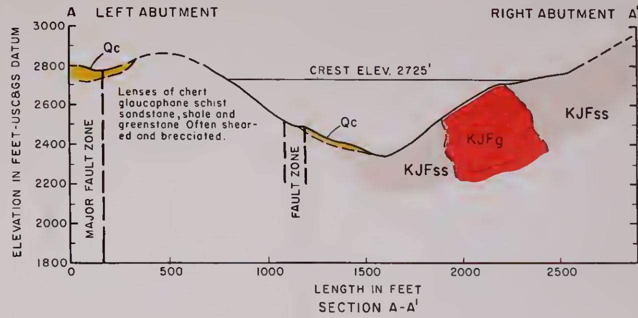
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION
EATON DAMSITE-VAN DUZEN RIVER

SCALE OF FEET
500 0 500

Contour Interval 20'





LEGEND

QUATERNARY — RECENT

- Qsw — SHALLOW COLLUVIUM – SOIL, SLOPEWASH AND SHALLOW LANDSLIDE DEPOSITS. GENERALLY SHALLOW AND LOCALLY DISCONTINUOUS.
- Qc — DEEP COLLUVIUM – DEEP ACCUMULATIONS OF SLOPEWASH AND LANDSLIDE DEBRIS. AVERAGE DEPTH IS MORE THAN 15 FEET. ACTIVE LANDSLIDE MOVEMENT IS INDICATED BY ARROWS.

FRANCISCAN GROUP

MESOZOIC — JURASSIC CRETACEOUS

- KJFss — SANDSTONE WITH SHALE INTERBEDS
- KJFc — CHERT – THINLY BEDDED TO MASSIVE.
- KJFg — GREENSTONE – ALTERED BASIC VOLCANIC ROCK.
- KJFsc — GLAUCOPHANE SCHIST AND ASSOCIATED METAMORPHIC ROCKS

SYMBOLS

- GEOLOGIC CONTACT – DASHED WHERE APPROXIMATE, DOTTED WHERE INDEFINITE OR INFERRED.
- 70 STRIKE AND DIP OF INCLINED STRATA.
- 60 ATTITUDE OF FOLIATION OR CLEAVAGE.
- FAULT – DOTTED WHERE INFERRED OR CONCEALED.
- A A' GEOLOGIC SECTION LINE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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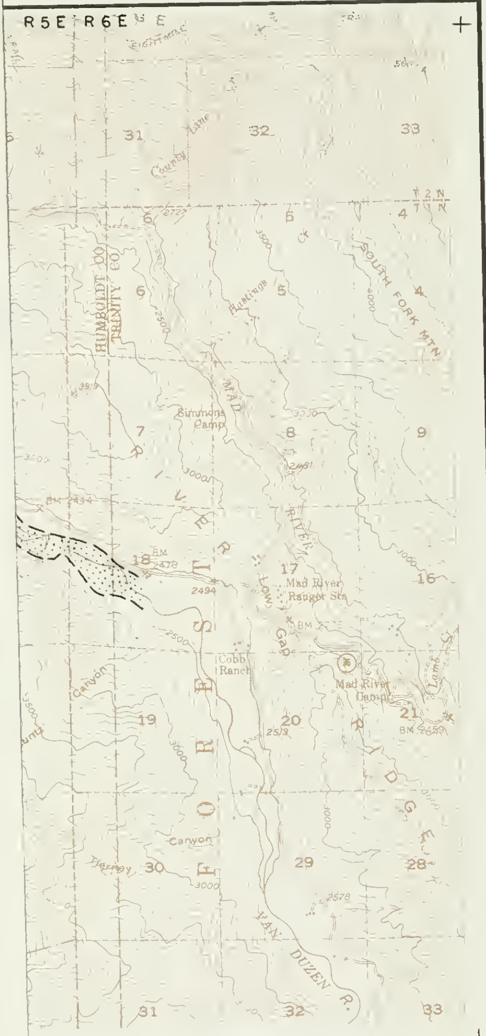
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION EATON DAMSITE-VAN DUZEN RIVER

SCALE OF FEET
500 0 500

Contour Interval 20'



STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

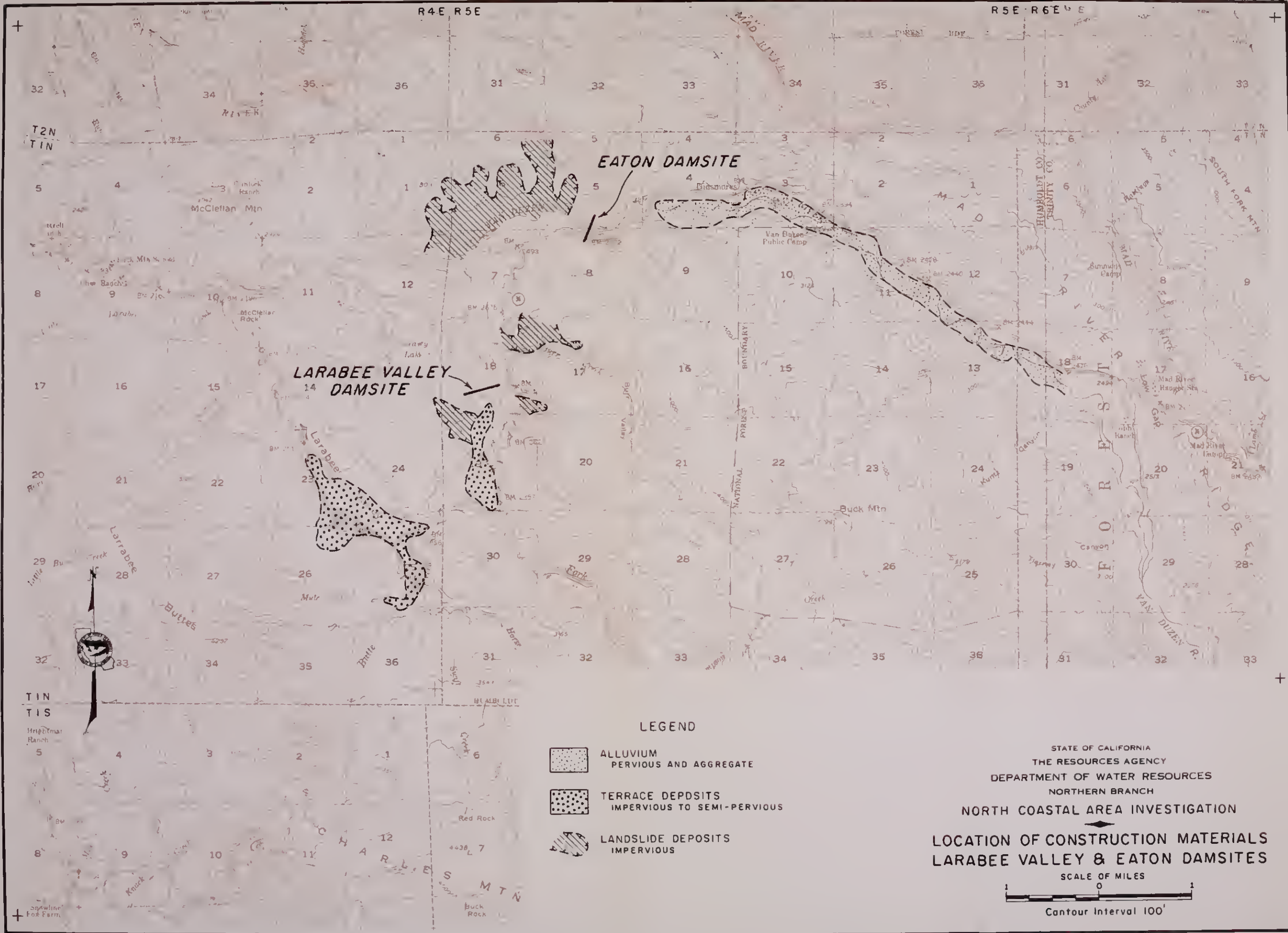
RTH COASTAL AREA INVESTIGATION

ON OF CONSTRUCTION MATERIALS
EE VALLEY & EATON DAMSITES

SCALE OF MILES

1 0 1

Contour Interval 100'

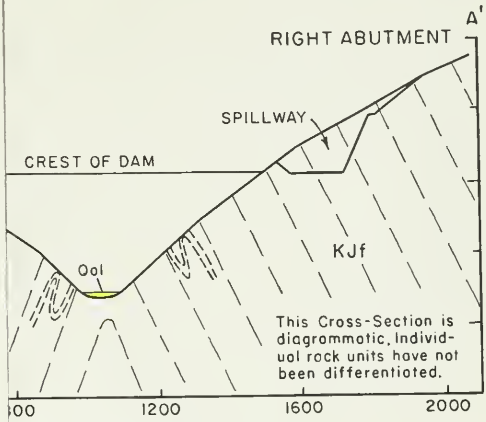


STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS LARABEE VALLEY & EATON DAMSITES

PLATE 39



LENGTH IN FEET

SECTION A-A'

LEGEND

VELS AND BOULDERS WITH LITTLE SAND

RMATION, UNDIFFERENTIATED
SSIVELY BEDDED, WELL CEMENTED SAND-
H THIN INTERBEDS OF MODERATELY WELL
FISSILE SLATY SHALE. SANDSTONE COM-
80% OF THE FOUNDATION.

SYMBOLS

CT BETWEEN ALLUVIUM AND BEDROCK.
TELY LOCATED

OF BEDS

HOWING STRIKE

OF JOINT PLANES

DSLIDE, APPROXIMATELY LOCATED

ON LINE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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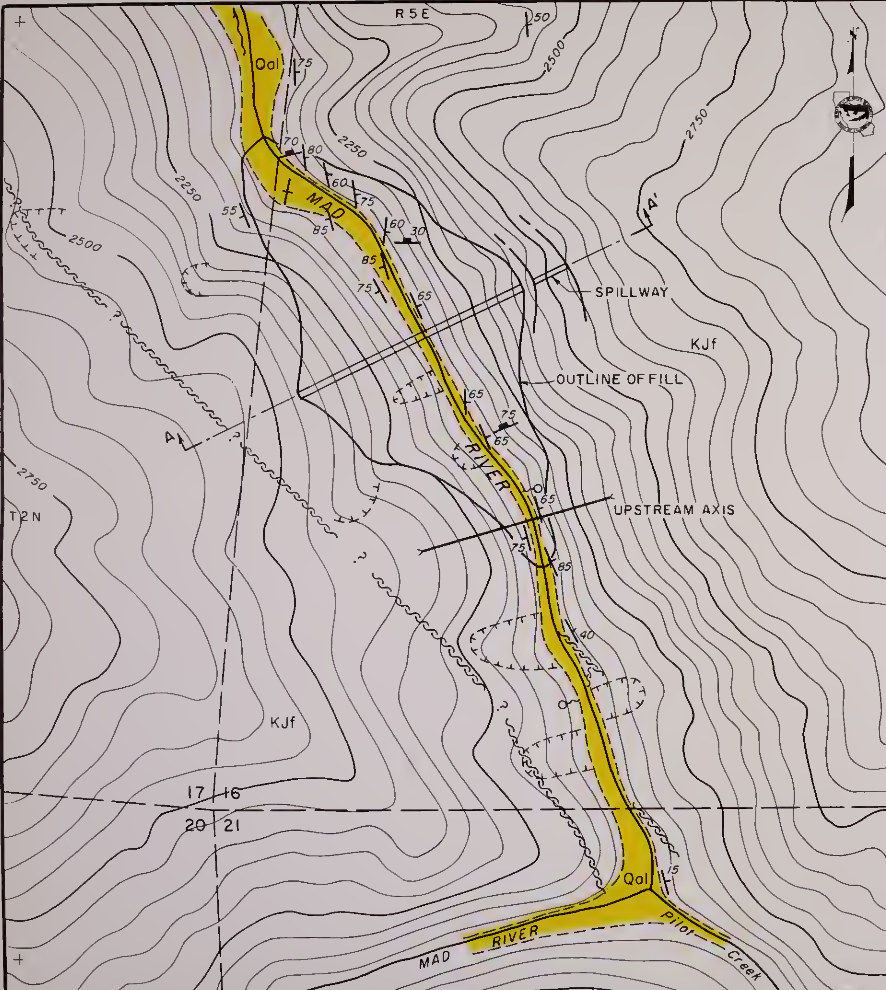
NORTHERN BRANCH

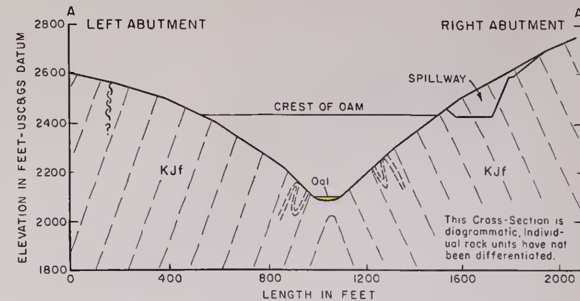
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION
NDERSON FORD DAMSITE — MAD RIVER

SCALE OF FEET
0 400 800

Contour Interval 50'





SECTION A-A'

LEGEND

Qal ALLUVIUM
COARSE GRAVELS AND BOULDERS WITH LITTLE SAND

KJf FRANCISCAN FORMATION, UNDIFFERENTIATED
THIN TO MASSIVELY BEDDED, WELL CEMENTED SANDSTONE, WITH THIN INTERBEDS OF MODERATELY WELL CEMENTED, FISSILE SLATY SHALE. SANDSTONE COMPRISES 70%–80% OF THE FOUNDATION.

SYMBOLS

GEOLOGIC CONTACT BETWEEN ALLUVIUM AND BEDROCK. APPROXIMATELY LOCATED

75 STRIKE AND DIP OF BEDS

VERTICAL BED SHOWING STRIKE

75 STRIKE AND DIP OF JOINT PLANES

SHEAR ZONE

OUTLINE OF LANDSLIDE, APPROXIMATELY LOCATED

SEEP OR SPRING

A A' GEOLOGIC SECTION LINE

STATE OF CALIFORNIA
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NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION
ANDERSON FORD DAMSITE – MAD RIVER

SCALE OF FEET
0 400 800

Contour Interval 50'

LEGEND

IMPERVIOUS BORROW AREA
LANDSLIDE DEBRIS AND SLOPEWASH

ROCKFILL AND RIPRAP SOURCE
MASSIVE GRAYWACKE SANDSTONE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

OCATION OF CONSTRUCTION MATERIALS
ANDERSON FORD DAMSITE

SCALE OF MILES
1 0 1

Contour Interval 50'

PLATE 40

LEGEND

I-2 IMPERVIOUS BORROW AREA
LANDSLIDE DEBRIS AND SLOPEWASH

R ROCKFILL AND RIPRAP SOURCE
MASSIVE GRAYWACKE SANDSTONE

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
ANDERSON FORD DAMSITE

SCALE OF MILES
1 0 1

Contour Interval 50'

LEGEND

FRANCISCAN FORMATION

ss	MASSIVE GRAYWACKE SANDSTONE WITH SUBORDINATE SHALE
sh	SHALE WITH SUBORDINATE SANDSTONE
fc	CHERT AND GREENSTONE
	GREENSTONE
ooo	CONGLOMERATE BEDS
u	GALICE FORMATION - MARINE SEDIMENTARY AND META-SEDIMENTARY ROCKS. SLATY AND PHYLLITIC SANDSTONE, SHALE AND MINOR CONGLOMERATE.
s	SOUTH FORK MOUNTAIN SCHIST - PRE-CRETACEOUS META-SEDIMENTARY ROCKS. THINLY FOLIATED QUARTZ MUSCOVITE AND CHLORITE SCHIST.

SYMBOLS

50	ALTITUDE OF BEDDING		FAULT
	VERTICAL BEDDING		THRUST FAULT
60	ALTITUDE OF CLEAVAGE		SHEAR ZONE
30	APPROXIMATE ALTITUDE OF CLEAVAGE		SPRING
	LITHOLOGIC CONTACT		LANDSLIDE

NE	ZONE I INCLUDES AREAS UNDERLAIN BY FRANCISCAN SANDSTONE WITH SUBORDINATE INTERBEDS OF SHALE. TUNNELING CONDITIONS WILL RANGE FROM MODERATELY BLOCKY AND SEAMY TO COMPLETELY CRUSHED.
I	ZONE II CONSISTS OF BELTS WITHIN THE FRANCISCAN FORMATION WHICH ARE UNDERLAIN BY A HIGH PERCENTAGE OF SHALE AND CHERT OR WHERE A HIGH DEGREE OF SHEARING WAS OBSERVED.
I	THIS TUNNELING ZONE CONSISTS OF THE SOUTH FORK MOUNTAIN SCHIST FORMATION. OWING TO POOR OUTCROPS THE PROPERTIES OF THIS UNIT WITH RESPECT TO TUNNELING ARE VIRTUALLY UNKNOWN.
Z	THIS ZONE CONSISTS OF SLATES AND PHYLLITES OF THE GALICE FORMATION. TUNNELING CONDITIONS WILL BE SCHISTOSE OR FOLIATED AND VERY BLOCKY AND SEAMY IN MINOR SHEARS.
	THIS ZONE DESCRIBES THE TUNNELING CONDITIONS WITHIN THE MAJOR FAULT ZONES PENETRATED BY THE PROPOSED TUNNEL LINES. EXTREMELY HAZARDOUS TUNNEL DRIVING IS ANTICIPATED. ABOUT 75 PERCENT OF ZONE V WILL BE "WET HEADING" TUNNELING.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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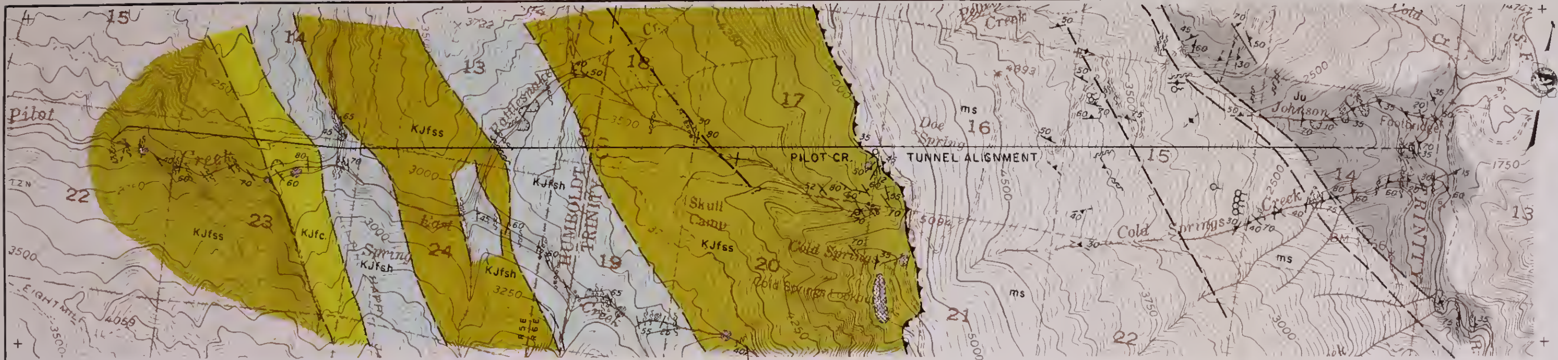
NORTH COASTAL AREA INVESTIGATION

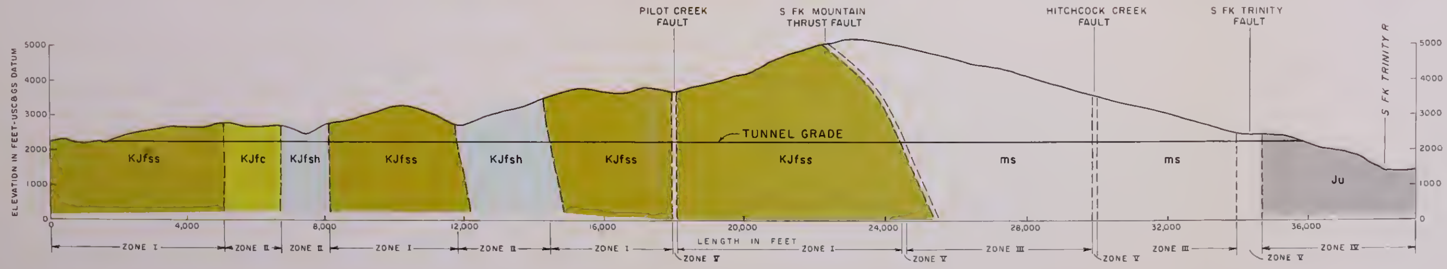
GEOLOGIC MAP AND SECTION
SOUTH FORK TUNNEL
PILOT CREEK ALIGNMENT

SCALE OF FEET

1000 0 1000 2000 3000 4000

Contour Interval 50'





GEOLOGIC SECTION ALONG TUNNEL ALIGNMENT

LEGEND

FRANCISCAN FORMATION

MESOZOIC

- KJfss — MASSIVE GRAYWACKE SANDSTONE WITH SUBORDINATE SHALE
- KJfsh — SHALE WITH SUBORDINATE SANDSTONE
- KJfc — CHERT AND GREENSTONE
- GREENSTONE
- CONGLOMERATE BEDS

UNDIVIDED

- Ju — GALICE FORMATION - MARINE SEDIMENTARY AND META-SEDIMENTARY ROCKS SLATY AND PHYLLITIC SANDSTONE SHALE AND MINOR CONGLOMERATE
- ms — SOUTH FORK MOUNTAIN SCHIST - PRE-CRETACEOUS META-SEDIMENTARY ROCKS THINLY FOLIATED QUARTZ MUSCOVITE AND CHLORITE SCHIST

SYMBOLS

- 50 ALTITUDE OF BEDDING
- VERTICAL BEDDING
- 60 ALTITUDE OF CLEAVAGE
- 30 APPROXIMATE ALTITUDE OF CLEAVAGE
- LITHOLOGIC CONTACT
- FAULT
- THRUST FAULT
- SHEAR ZONE
- SPRING
- LANDSLIDE

ZONE	
I	ZONE I INCLUDES AREAS UNDERLAIN BY FRANCISCAN SANDSTONE WITH SUBORDINATE INTERBEDS OF SHALE. TUNNELING CONDITIONS WILL RANGE FROM MODERATELY BLOCKY AND SEAMY TO COMPLETELY CRUSHED
II	ZONE II CONSISTS OF BELTS WITHIN THE FRANCISCAN FORMATION WHICH ARE UNDERLAIN BY A HIGH PERCENTAGE OF SHALE AND CHERT OR WHERE A HIGH DEGREE OF SHEARING WAS OBSERVED
III	THIS TUNNELING ZONE CONSISTS OF THE SOUTH FORK MOUNTAIN SCHIST FORMATION. OWING TO POOR OUTCROPS THE PROPERTIES OF THIS UNIT WITH RESPECT TO TUNNELING ARE VIRTUALLY UNKNOWN
IV	THIS ZONE CONSISTS OF SLATES AND PHYLLITES OF THE GALICE FORMATION. TUNNELING CONDITIONS WILL BE SCHISTOSE OR FOLIATED AND VERY BLOCKY AND SEAMY IN MINOR SHEARS.
V	THIS ZONE DESCRIBES THE TUNNELING CONDITIONS WITHIN THE MAJOR FAULT ZONES PENETRATED BY THE PROPOSED TUNNEL LINES. EXTREMELY HAZARDOUS TUNNEL DRIVING IS ANTICIPATED. ABOUT 75 PERCENT OF ZONE V WILL BE "WET HEADING" TUNNELING

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THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
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GEOLOGIC MAP AND SECTION
SOUTH FORK TUNNEL
PILOT CREEK ALIGNMENT

SCALE OF FEET
1000 0 1000 2000 3000 4000

Contour Interval 50'

LEGEND

Jf — FRANCISCAN FORMATION - MASSIVE GRAYWACKE AND MINOR AMOUNTS OF SHALE, THIN BEDDED CHERT, GREENSTONE AND GLAUCOPHANE SCHIST.

u — GALICE FORMATION - MARINE SEDIMENTARY AND META-SEDIMENTARY ROCKS SLATY AND PHYLLITIC SANDSTONE, SHALE AND MINOR CONGLOMERATE

s — SOUTH FORK MOUNTAIN SCHIST - PRE-CRETACEOUS META-SEDIMENTARY ROCKS. THINLY FOLIATED QUARTZ MUSCOVITE AND CHLORITE SCHIST.

SYMBOLS

FAULT

FAULT, APPROXIMATELY LOCATED (DASHED) AND QUESTIONABLE (?).

THRUST FAULT.

NE	
I	ZONE I INCLUDES AREAS UNDERLAIN BY FRANCISCAN SANDSTONE WITH SUBORDINATE INTERBEDS OF SHALE. TUNNELING CONDITIONS WILL RANGE FROM MODERATELY BLOCKY AND SEAMY TO COMPLETELY CRUSHED
II	ZONE II CONSISTS OF BELTS WITHIN THE FRANCISCAN FORMATION WHICH ARE UNDERLAIN BY A HIGH PERCENTAGE OF SHALE OR WHERE A HIGH DEGREE OF SHEARING WAS OBSERVED
III	THIS TUNNELING ZONE CONSISTS OF THE SOUTH FORK MOUNTAIN SCHIST FORMATION. OWING TO POOR OUTCROPS THE PROPERTIES OF THIS UNIT WITH RESPECT TO TUNNELING ARE VIRTUALLY UNKNOWN
IV	THIS ZONE CONSISTS OF A PORTION OF THE SOUTH FORK MOUNTAIN FAULT ZONE. TUNNELING CONDITIONS WILL BE VERY BLOCKY AND SEAMY
V	THIS ZONE DESCRIBES THE TUNNELING CONDITIONS WITHIN THE MAJOR FAULT ZONES PENETRATED BY THE PROPOSED TUNNEL LINES. EXTREMELY HAZARDOUS TUNNEL DRIVING IS ANTICIPATED. ABOUT 75 PERCENT OF ZONE V WILL BE "WET HEADING" TUNNELING

NOTE: GEOLOGIC FEATURES AND TUNNELING CONDITIONS ZONES ARE BASED UPON DATA OBTAINED FROM "GEOLOGICAL ENGINEERING STUDY OF PROPOSED TUNNEL THROUGH SOUTH FORK MOUNTAIN, TRINITY COUNTY, CALIFORNIA" BY LOUIS V. GIRARD, AND "GEOLOGICAL MAP OF CALIFORNIA, REDDING SHEET," CALIFORNIA STATE DIVISION OF MINES AND GEOLOGY.

STATE OF CALIFORNIA
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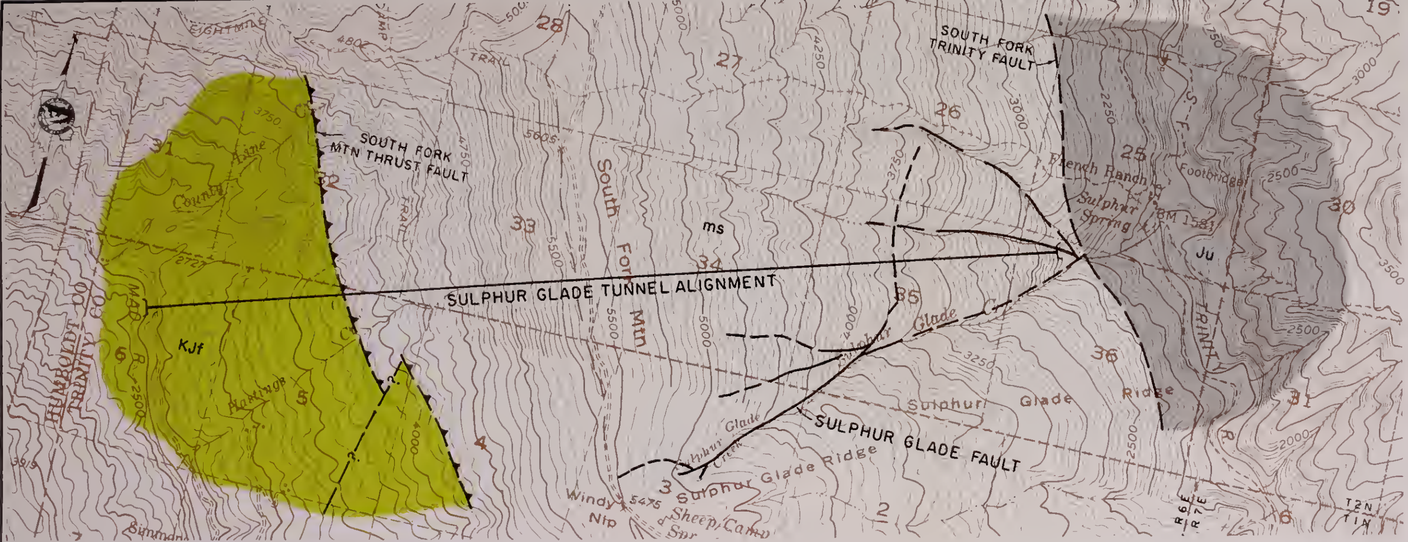
NORTHERN BRANCH

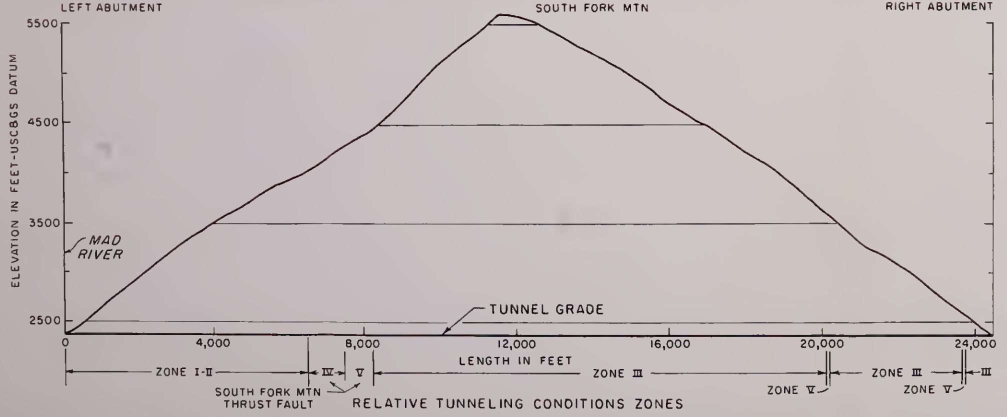
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION SOUTH FORK TUNNEL SULPHUR GLADE ALIGNMENT

SCALE OF FEET
2000 0 2000 4000

Contour Interval 50'





LEGEND

MESOZOIC

- **KJf** — FRANCISCAN FORMATION - MASSIVE GRAYWACKE AND MINOR AMOUNTS OF SHALE, THIN BEDDED CHERT, GREENSTONE AND GLAUCOPHANE SCHIST.
- **Ju** — GALICE FORMATION - MARINE SEDIMENTARY AND META-SEDIMENTARY ROCKS SLATY AND PHYLLITIC SANDSTONE, SHALE AND MINOR CONGLOMERATE

UNDIVIDED

- **ms** — SOUTH FORK MOUNTAIN SCHIST - PRE-CRETACEOUS META-SEDIMENTARY ROCKS. THINLY FOLIATED QUARTZ MUSCOVITE AND CHLORITE SCHIST.

SYMBOLS

- FAULT
- FAULT, APPROXIMATELY LOCATED (DASHED) AND QUESTIONABLE (?).
- THRUST FAULT.

ZONE	
I	ZONE I INCLUDES AREAS UNDERLAIN BY FRANCISCAN SANDSTONE WITH SUBORDINATE INTERBEDS OF SHALE. TUNNELING CONDITIONS WILL RANGE FROM MODERATELY BLOCKY AND SEAMY TO COMPLETELY CRUSHED
II	ZONE II CONSISTS OF BELTS WITHIN THE FRANCISCAN FORMATION WHICH ARE UNDERLAIN BY A HIGH PERCENTAGE OF SHALE OR WHERE A HIGH DEGREE OF SHEARING WAS OBSERVED
III	THIS TUNNELING ZONE CONSISTS OF THE SOUTH FORK MOUNTAIN SCHIST FORMATION. OWING TO POOR OUTCROPS THE PROPERTIES OF THIS UNIT WITH RESPECT TO TUNNELING ARE VIRTUALLY UNKNOWN
IV	THIS ZONE CONSISTS OF A PORTION OF THE SOUTH FORK MOUNTAIN FAULT ZONE. TUNNELING CONDITIONS WILL BE VERY BLOCKY AND SEAMY
V	THIS ZONE DESCRIBES THE TUNNELING CONDITIONS WITHIN THE MAJOR FAULT ZONES PENETRATED BY THE PROPOSED TUNNEL LINES. EXTREMELY HAZARDOUS TUNNEL DRIVING IS ANTICIPATED. ABOUT 75 PERCENT OF ZONE V WILL BE "WET HEADING" TUNNELING

NOTE: GEOLOGIC FEATURES AND TUNNELING CONDITIONS ZONES ARE BASED UPON DATA OBTAINED FROM "GEOLOGICAL ENGINEERING STUDY OF PROPOSED TUNNEL THROUGH SOUTH FORK MOUNTAIN, TRINITY COUNTY, CALIFORNIA" BY LOUIS V. GIRARD, AND "GEOLOGICAL MAP OF CALIFORNIA, REDDING SHEET," CALIFORNIA STATE DIVISION OF MINES AND GEOLOGY.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTION
SOUTH FORK TUNNEL
SULPHUR GLADE ALIGNMENT

SCALE OF FEET
2000 0 2000 4000

Contour Interval 50'

LEGEND

Qc	QUATERNARY STREAM CHANNEL DEPOSITS. LOOSE COARSE SAND AND GRAVEL ALONG THE CHANNEL.
Qyal	QUATERNARY YOUNGER ALLUVIUM. SANDY-SILT, SILTY-CLAY AND SOME MEDIUM TO COARSE SAND AND GRAVEL.
Tt	TERTIARY TEHAMA FORMATION. MODERATELY COMPACTED SILT, CLAY, SAND AND GRAVEL. ABOUT HALF SILT AND CLAY AND HALF SAND AND GRAVEL.
Ts	TERTIARY SEDIMENTARY ROCKS. UNDIFFERENTIATED SANDSTONE, SILTSTONE, SHALE, AND CONGLOMERATE.
Tb	TERTIARY BASALT. DARK, DENSE BASALT AT PUTNAM PEAK.
Kc	CRETACEOUS CHICO FORMATION. SHALE, SILTSTONE, SANDSTONE, AND MINOR AMOUNTS OF CONGLOMERATE. SANDSTONE, SHALE-SILTSTONE RATIO ABOUT 40% TO 60% EXCEPT NEAR BASE WHERE SANDSTONE IS PREDOMINATE.
Ks	CRETACEOUS SHASTA FORMATION. PREDOMINANTLY SHALE AND SILTSTONE WITH SMALL AMOUNTS OF INTERBEDDED SANDSTONE AND CONGLOMERATE.
	APPROXIMATE GEOLOGIC CONTACT
2	PROPOSED BORROW AREA IMPERVIOUS – AREAS 1 AND 2 IMPERVIOUS TO SEMIPERVIOUS – AREA 3 ROCKFILL OR RIPRAP – AREAS 4, 5, AND 6.

NOTE:
GEOLOGY IN PART BY THE U.S. GEOLOGICAL SURVEY.

STATE OF CALIFORNIA
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NORTHERN BRANCH

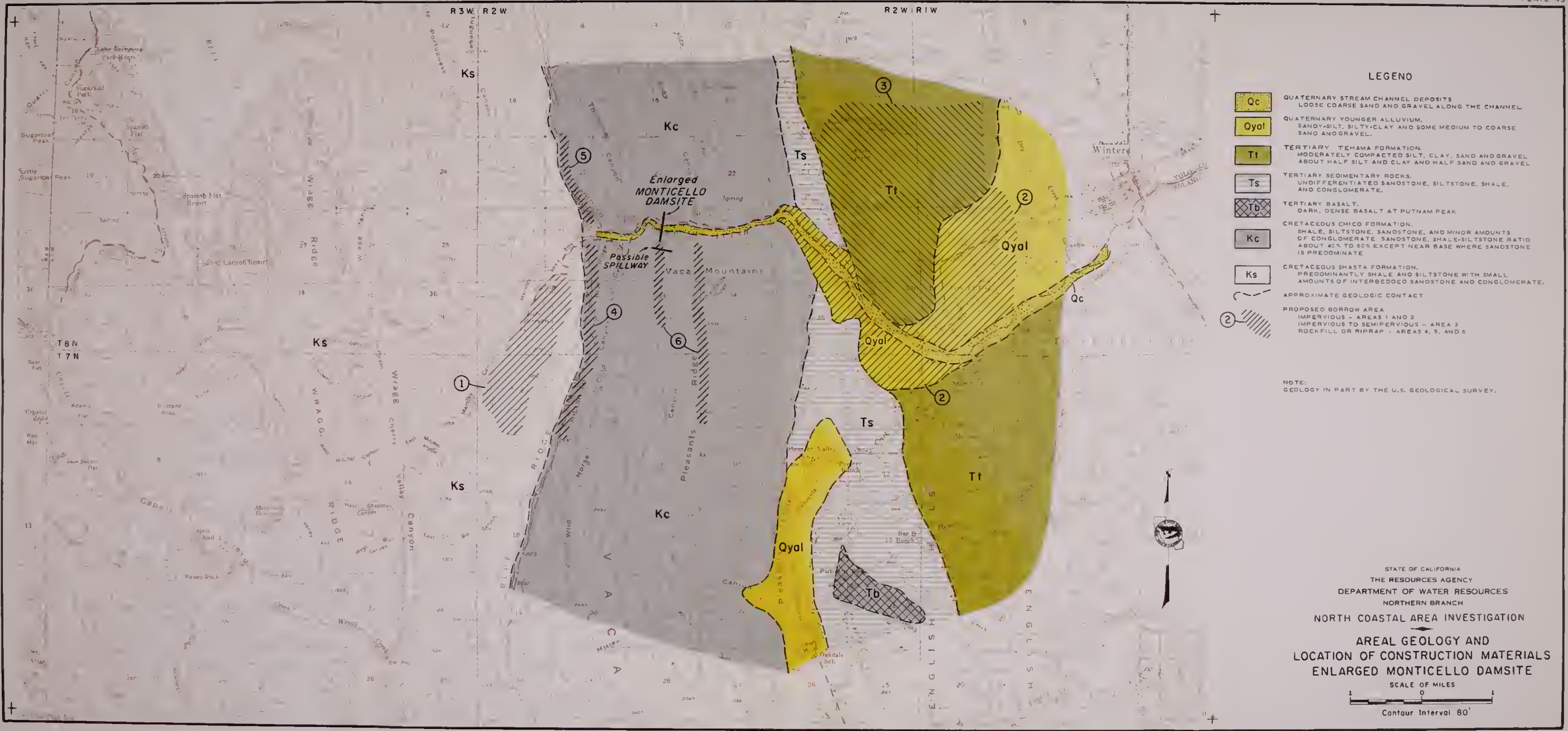
NORTH COASTAL AREA INVESTIGATION

AREAL GEOLOGY AND LOCATION OF CONSTRUCTION MATERIALS ENLARGED MONTICELLO DAMSITE

SCALE OF MILES

1 0 1

Contour Interval 80'


R3W R2W
R2W R1W
Ks
Kc
Ts
Tt
Qyal
Qc
Tb
Enlarged
MONTICELLO
DAMSITE
Possible
SPILLWAY
Vaca Mountains
T8N
T7N
LEGENO
Qc
QUATERNARY STREAM CHANNEL DEPOSITS
LOOSE COARSE SANO ANO GRAVEL ALONG THE CHANNEL.
Qyal
QUATERNARY YOUNGER ALLUVIUM.
SANOY-SILT, SILTY-CLAY ANO SOME MEOIUM TO COARSE SANO ANO GRAVEL.
Tt
TERTIARY TEHAMA FORMATION.
MODERATELY COMPACTED SILT, CLAY, SAND ANO GRAVEL ABOUT HALF SILT AND CLAY AND HALF SAND ANO GRAVEL
Ts
TERTIARY SEOIMENTARY ROCKS.
UNDIFFERENTIATEO SANOSTONE, SILTSTONE, SHALE, ANO CONGLOMERATE.
Tb
TERTIARY BASALT.
OARK, OENSE BASALT AT PUTNAM PEAK
Kc
CRETACEOUS CHICO FORMATION.
SHALE, SILTSTONE, SANOSTONE, AND MINOR AMOUNTS OF CONGLOMERATE SANOSTONE, SHALE-SILTSTONE RATIO ABOUT 40% TO 60% EXCEPT NEAR BASE WHERE SANOSTONE IS PREDOMINATE
Ks
CRETACEOUS SHASTA FORMATION.
PREOOMINANTLY SHALE ANO SILTSTONE WITH SMALL AMOUNTS OF INTERBEOOEO SANOSTONE ANO CONGLOMERATE.
APPROXIMATE GEOLOGIC CONTACT
PROPOSEO BORROW AREA
IMPERVIOUS - AREAS 1 ANO 2
IMPERVIOUS TO SEMIPERVIOUS - AREA 3
ROCKFILL OR RIPRAP - AREAS 4, 5, AND 6
NOTE:
GEOLOGY IN PART BY THE U.S. GEOLOGICAL SURVEY.
STATE OF CALIFORNIA
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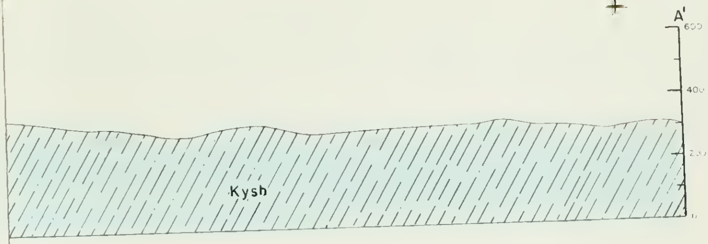
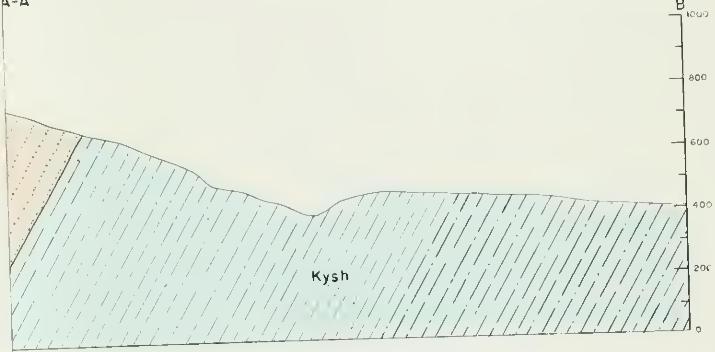
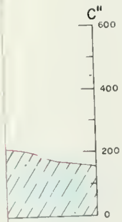
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
AREAL GEOLOGY AND
LOCATION OF CONSTRUCTION MATERIALS
ENLARGED MONTICELLO DAMSITE
SCALE OF MILES
1 0 1
Contour Interval 80'

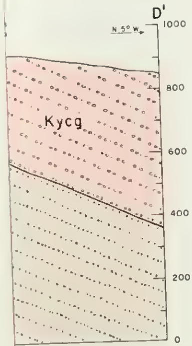


A-A'



B-B'





LEGEND

QUATERNARY

Qal ALLUVIUM
UNCONSOLIDATED, POORLY SORTED STREAM SANDS AND GRAVELS

CRETACEOUS

Kycg YAGER CONGLOMERATE
CONGLOMERATE CONSISTING OF FRAGMENTS RANGING IN SIZE FROM GRANULES TO BOULDERS CEMENTED BY A SANDSTONE MATRIX. CONTAINS SOME INTERBEDDED SANDSTONE

Kyss YAGER SANDSTONE
WELL CEMENTED HARD GRAY PREDOMINATELY MEDIUM-GRAINED SANDSTONE

Kysh YAGER SHALE
BLACK THINLY BEDDED SHALE INTERBEDDED WITH LESSER AMOUNTS OF THINLY BEDDED SANDSTONE

UPPER JURASSIC OR LOWER CRETACEOUS

Jf FRANCISCAN SANDSTONE AND SHALE
MASSIVE GRAYWACKE SANDSTONE WITH SOME BLACK SHALE AND CHERT, STRUCTURALLY MORE COMPLEX THAN THE YAGER FORMATION

SYMBOLS

58 STRIKE AND DIP OF BEDS
43 STRIKE AND DIP OF JOINTS
ALLUVIAL CONTACT
LITHOLOGIC CONTACT, DASHED WHERE APPROXIMATELY LOCATED
FAULT (U, UPTHROWN SIDE, D, DOWNTHROWN SIDE
SHEAR ZONE
SPRING
S-1 VERTICAL CORE HOLE
RC-1 INCLINED CORE HOLE SHOWING BOTTOM LOCATION
A A' GEOLOGIC SECTION LINE

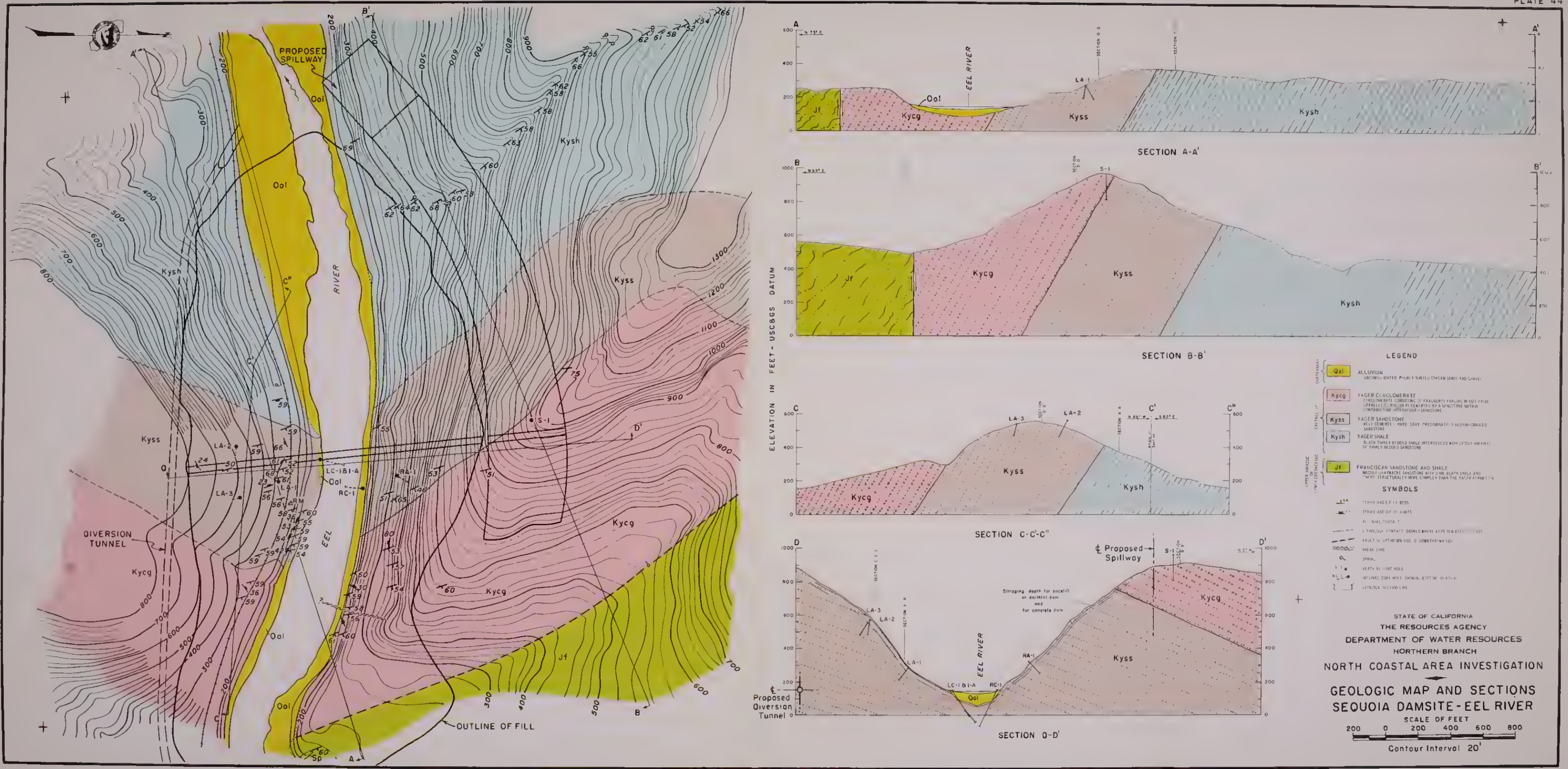
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS SEQUOIA DAMSITE-EEL RIVER

SCALE OF FEET
200 0 200 400 600 800

Contour Interval 20'


PROPOSED SPILLWAY
EEL RIVER
DIVERSION TUNNEL
OUTLINE OF FILL
Qal
Kysh
Kyss
Kycg
Jf
SECTION A-A'
SECTION B-B'
SECTION C-C'-C"
SECTION D-D'
ELEVATION IN FEET - USC&GS DATUM
℄ Proposed Spillway
℄ Proposed Diversion Tunnel
LEGEND
ALLUVIUM
YAGER CONGLOMERATE
YAGER SANDSTONE
YAGER SHALE
FRANCISCAN SANDSTONE AND SHALE
SYMBOLS
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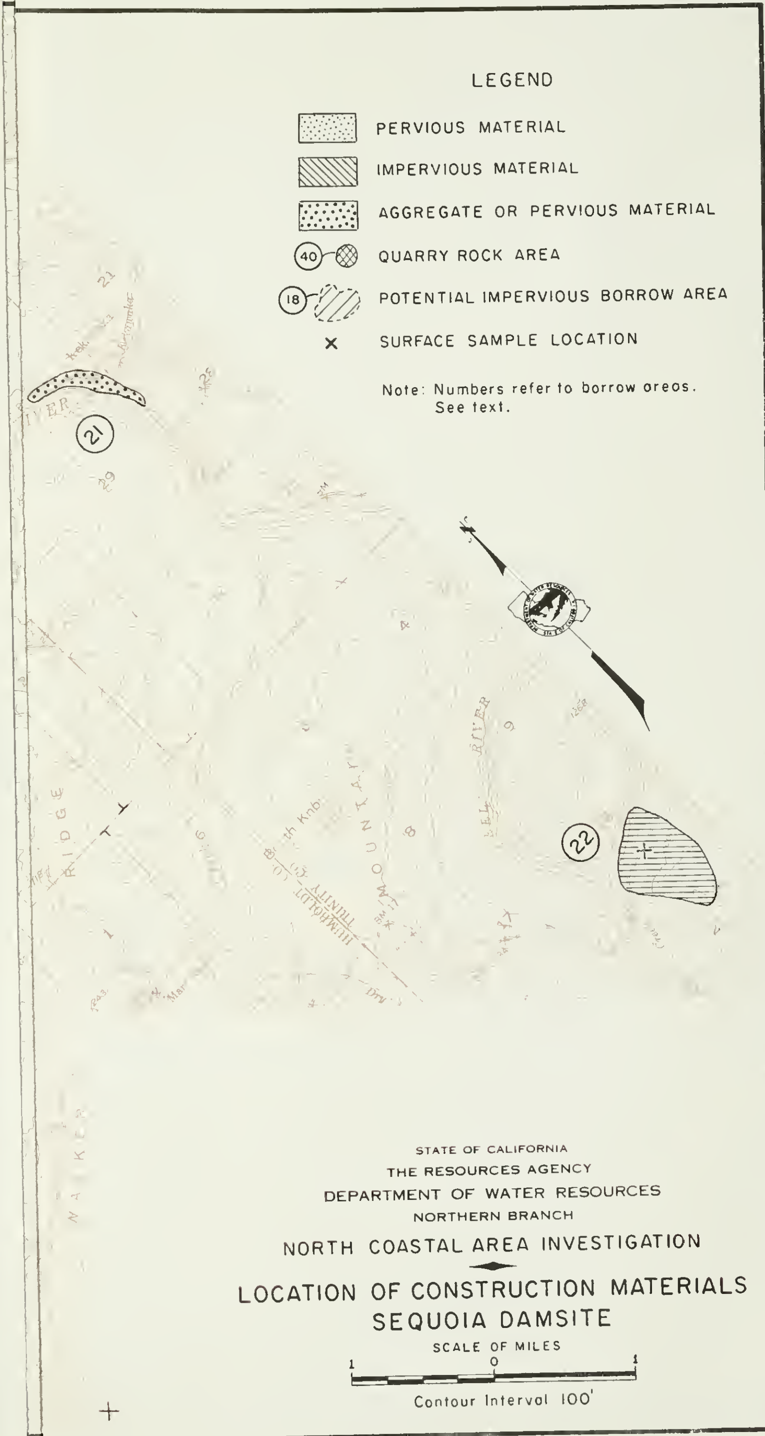
NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTIONS
SEQUOIA DAMSITE - EEL RIVER
SCALE OF FEET
200 0 200 400 600 800
Contour Interval 20'


LEGEND
PERVIOUS MATERIAL
IMPERVIOUS MATERIAL
AGGREGATE OR PERVIOUS MATERIAL
40
QUARRY ROCK AREA
18
POTENTIAL IMPERVIOUS BORROW AREA
SURFACE SAMPLE LOCATION
Note: Numbers refer to borrow oreos. See text.
21
22
STATE OF CALIFORNIA
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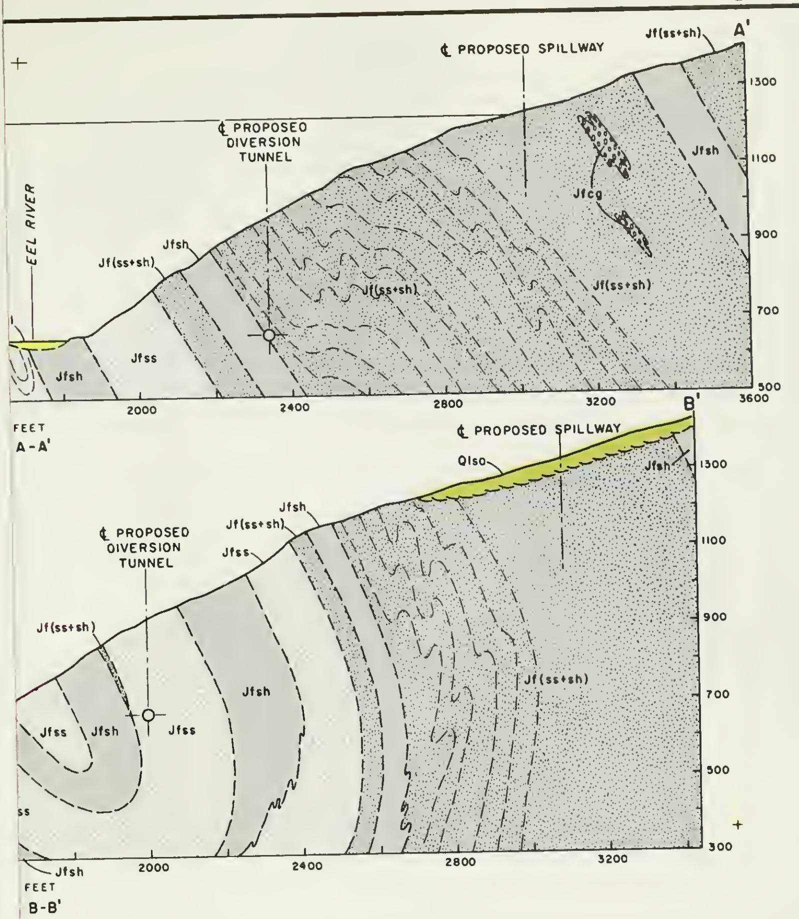
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
LOCATION OF CONSTRUCTION MATERIALS
SEQUOIA DAMSITE
SCALE OF MILES
1
0
1
Contour Interval 100'


SEQUOIA DAMSITE
LEGEND
PERVIOUS MATERIAL
IMPERVIOUS MATERIAL
AGGREGATE OR PERVIOUS MATERIAL
QUARRY ROCK AREA
POTENTIAL IMPERVIOUS BORROW AREA
SURFACE SAMPLE LOCATION
Note Numbers refer to borrow areas
See text
STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES
NORTHERN BRANCH
NORTH COASTAL AREA INVESTIGATION
LOCATION OF CONSTRUCTION MATERIALS
SEQUOIA DAMSITE
SCALE OF MILES
1 0 1
Contour Interval 100



ALL ANTICLINE AND SYNCLINE

ALL OVERTURNED SYNCLINE, SHOWING DIP OF AXIAL PLANE AND DEGREE OF PLUNGE

AJOR OVERTURNED SYNCLINE. (?) WHERE DOUBTFUL

AJOR OVERTURNED ANTICLINE

EOLOGIC SECTION LINE

OTE: SOME CROSS SECTION ROCK UNITS ARE EXTRAPOLATED BENEATH SLOPE WASH FROM STREAMSIDE EXPOSURES

STATE OF CALIFORNIA
THE RESOURCES AGENCY
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NORTHERN BRANCH

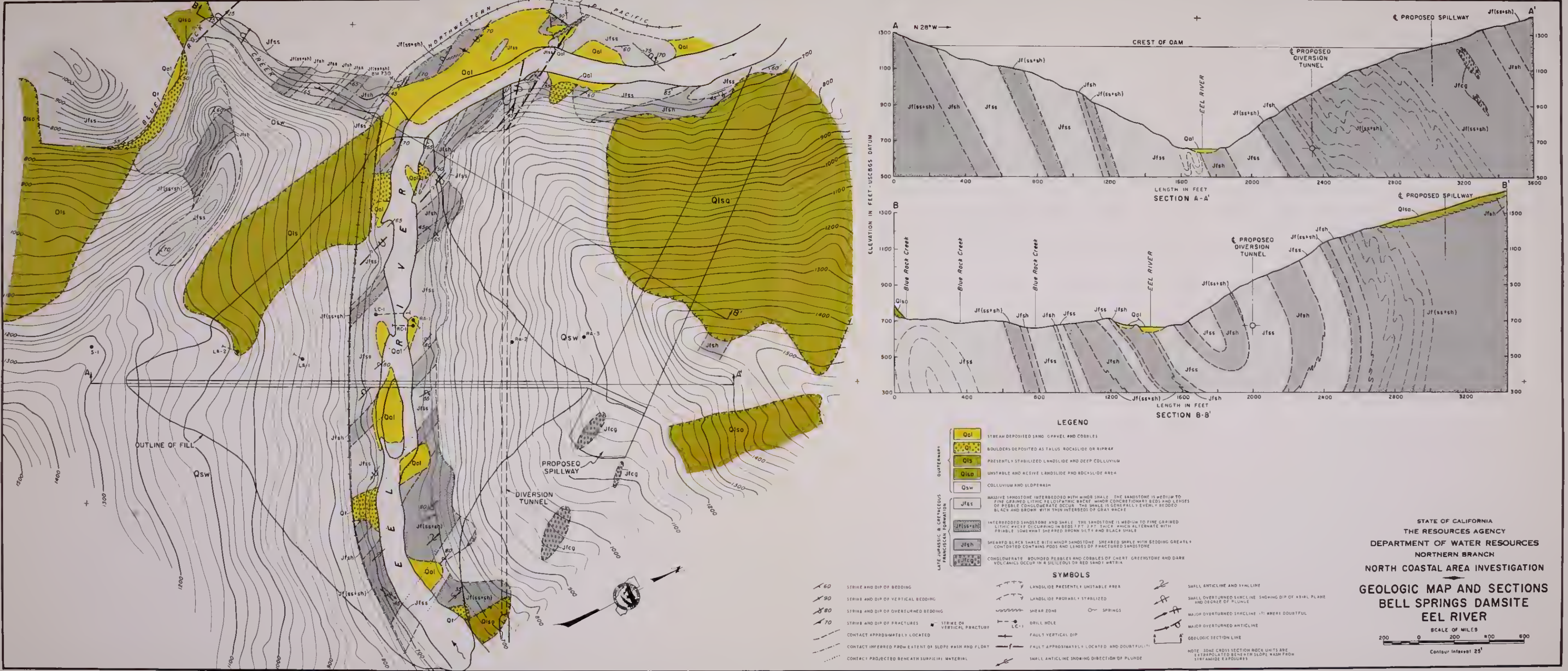
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS BELL SPRINGS DAMSITE EEL RIVER

SCALE OF MILES

200 0 200 400 600

Contour Interval 25'


SECTION A-A'
SECTION B-B'
CREST OF DAM
PROPOSED SPILLWAY
PROPOSED DIVERSION TUNNEL
EEL RIVER
Blue Rock Creek
ELEVATION IN FEET - USC&GS DATUM
LENGTH IN FEET
N 28° W
OUTLINE OF FILL
NORTHWESTERN PACIFIC
BLUE ROCK CREEK
LEGEND
QUATERNARY
Qal STREAM DEPOSITED SAND, GRAVEL AND COBBLES
Qt BOULDERS DEPOSITED AS TALUS, ROCKSLIDE OR RIPRAP
Qls PRESENTLY STABILIZED LANDSLIDE AND DEEP COLLUVIUM
Qlsa UNSTABLE AND ACTIVE LANDSLIDE AND ROCKSLIDE AREA
Qsw COLLUVIUM AND SLOPEWASH
LATE JURASSIC & CRETACEOUS FRANCISCAN FORMATION
Jfss MASSIVE SANDSTONE INTERBEDDED WITH MINOR SHALE. THE SANDSTONE IS MEDIUM TO FINE GRAINED LITHIC FELDSPATHIC WACKE. MINOR CONCRETIONARY BEDS AND LENSES OF PEBBLE CONGLOMERATE OCCUR. THE SHALE IS GENERALLY EVENLY BEDDED BLACK AND BROWN WITH THIN INTERBEDS OF GRAYWACKE
Jf(ss+sh) INTERBEDDED SANDSTONE AND SHALE. THE SANDSTONE IS MEDIUM TO FINE GRAINED LITHIC WACKE OCCURRING IN BEDS 1 FT - 3 FT THICK WHICH ALTERNATE WITH FRIABLE, SOMEWHAT SHEARED BROWN SILTY AND BLACK SHALE
Jfsh SHEARED BLACK SHALE WITH MINOR SANDSTONE. SHEARED SHALE WITH BEDDING GREATLY CONTORTED CONTAINS PODS AND LENSES OF FRACTURED SANDSTONE
Jfcg CONGLOMERATE. ROUNDED PEBBLES AND COBBLES OF CHERT, GREENSTONE AND DARK VOLCANICS OCCUR IN A SILICEOUS OR RED SANDY MATRIX
SYMBOLS
STRIKE AND DIP OF BEDDING
STRIKE AND DIP OF VERTICAL BEDDING
STRIKE AND DIP OF OVERTURNED BEDDING
STRIKE AND DIP OF FRACTURES
STRIKE OF VERTICAL FRACTURE
CONTACT APPROXIMATELY LOCATED
CONTACT INFERRED FROM EXTENT OF SLOPE WASH AND FLOAT
CONTACT PROJECTED BENEATH SURFICIAL MATERIAL
LANDSLIDE PRESENTLY UNSTABLE AREA
LANDSLIDE PROBABLY STABILIZED
SHEAR ZONE
SPRINGS
DRILL HOLE
FAULT VERTICAL DIP
FAULT APPROXIMATELY LOCATED AND DOUBTFUL
SMALL ANTICLINE SHOWING DIRECTION OF PLUNGE
SMALL ANTICLINE AND SYNCLINE
SMALL OVERTURNED SYNCLINE SHOWING DIP OF AXIAL PLANE AND DEGREE OF PLUNGE
MAJOR OVERTURNED SYNCLINE (?) WHERE DOUBTFUL
MAJOR OVERTURNED ANTICLINE
GEOLOGIC SECTION LINE
NOTE: SOME CROSS SECTION ROCK UNITS ARE EXTRAPOLATED BENEATH SLOPE WASH FROM STREAMSIDE EXPOSURES
STATE OF CALIFORNIA
THE RESOURCES AGENCY
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NORTH COASTAL AREA INVESTIGATION
GEOLOGIC MAP AND SECTIONS
BELL SPRINGS DAMSITE
EEL RIVER
SCALE OF MILES
Contour Interval 25'

LEGEND

IMPERVIOUS SOURCE - LANDSIDE DEBRIS

PERVIOUS SOURCE - STREAM GRAVELS

ROCKFILL SOURCE - QUARRYABLE ROCK - SANDSTONE AND SHALE, GREENSTONE AND CHERTS.

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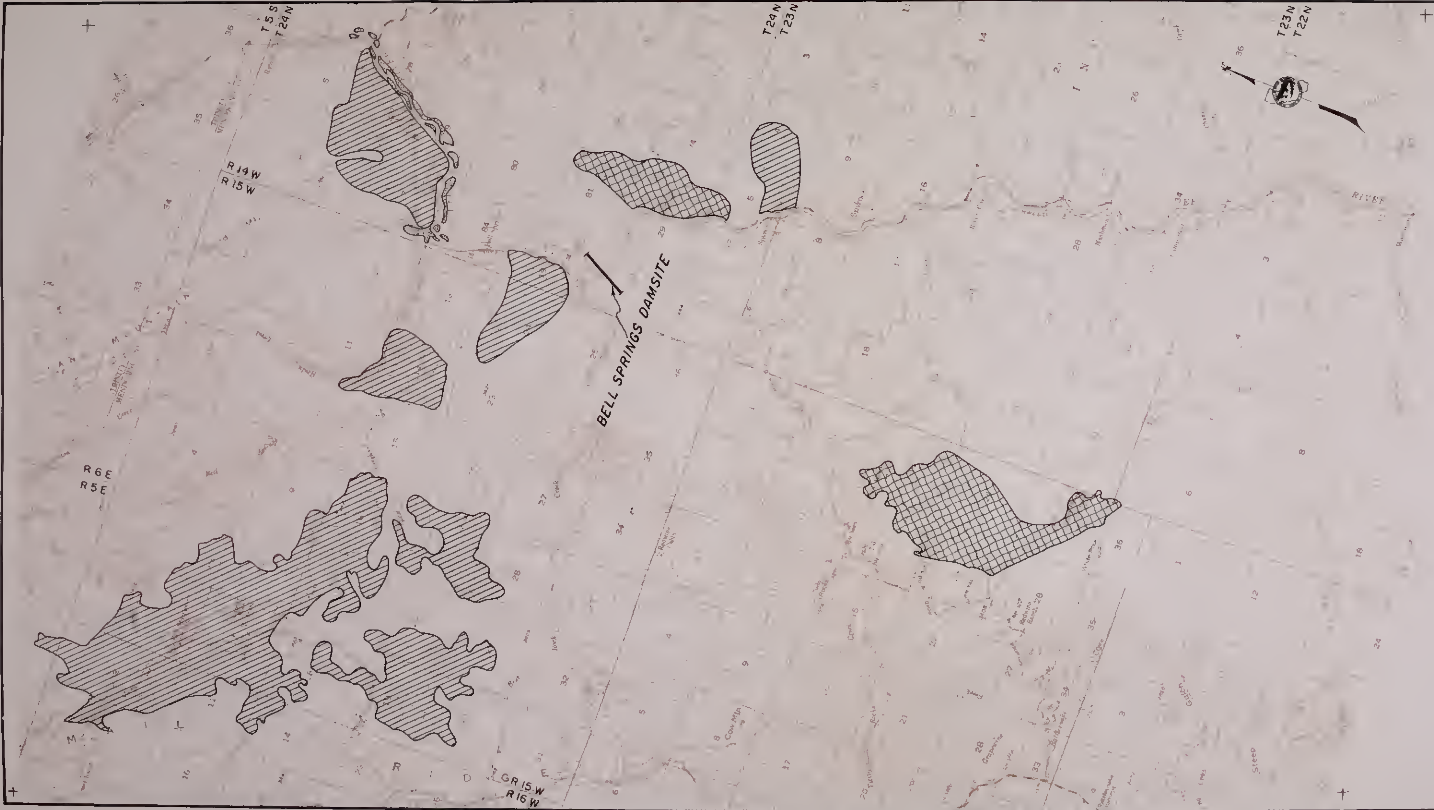
NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
BELL SPRINGS DAMSITE

SCALE OF MILES

1 0 1

Contour Interval 100'



LEGEND

- IMPERVIOUS SOURCE - LANDSIDE DEBRIS
- PERVIOUS SOURCE - STREAM GRAVELS
- ROCKFILL SOURCE - QUARRYABLE ROCK - SANDSTONE AND SHALE, GREENSTONE AND CHERTS

STATE OF CALIFORNIA
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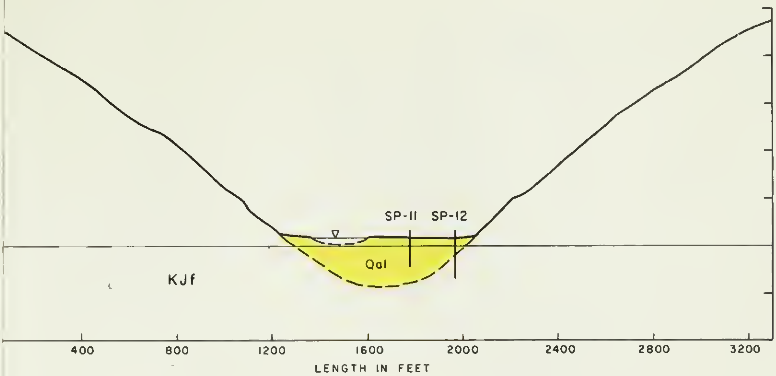
NORTH COASTAL AREA INVESTIGATION

LOCATION OF CONSTRUCTION MATERIALS
BELL SPRINGS DAMSITE

SCALE OF MILES
1 0 1

Contour Interval 100'



ALONG AXIS OF DAM

LEGEND

PLEISTOCENE TO RECENT

Qal — STREAM CHANNEL ALLUVIUM
UNCONSOLIDATED SAND AND GRAVEL WITH OCCASIONAL SILTY LENSES.

JURA-CRETACEOUS

KJf — FRANCISCAN GROUP UNDIFFERENTIATED
PREDOMINENTLY GRAYWACKE SANDSTONE WITH THIN SHALE INTERBEDS.

OUTCROPS OF FRANCISCAN GRAYWACKE
CONFINED TO THE STREAM CHANNEL. THE ABUTMENTS ARE COVERED BY A DEEP MANTLE OF SOIL AND COLLUVIUM. THE VEGETATION COVER IS EXTREMELY DENSE.

SP-11 — SP-12 SEISMIC EXPLORATION LINES.

A — A' GEOLOGIC SECTION LINE.

STATE OF CALIFORNIA
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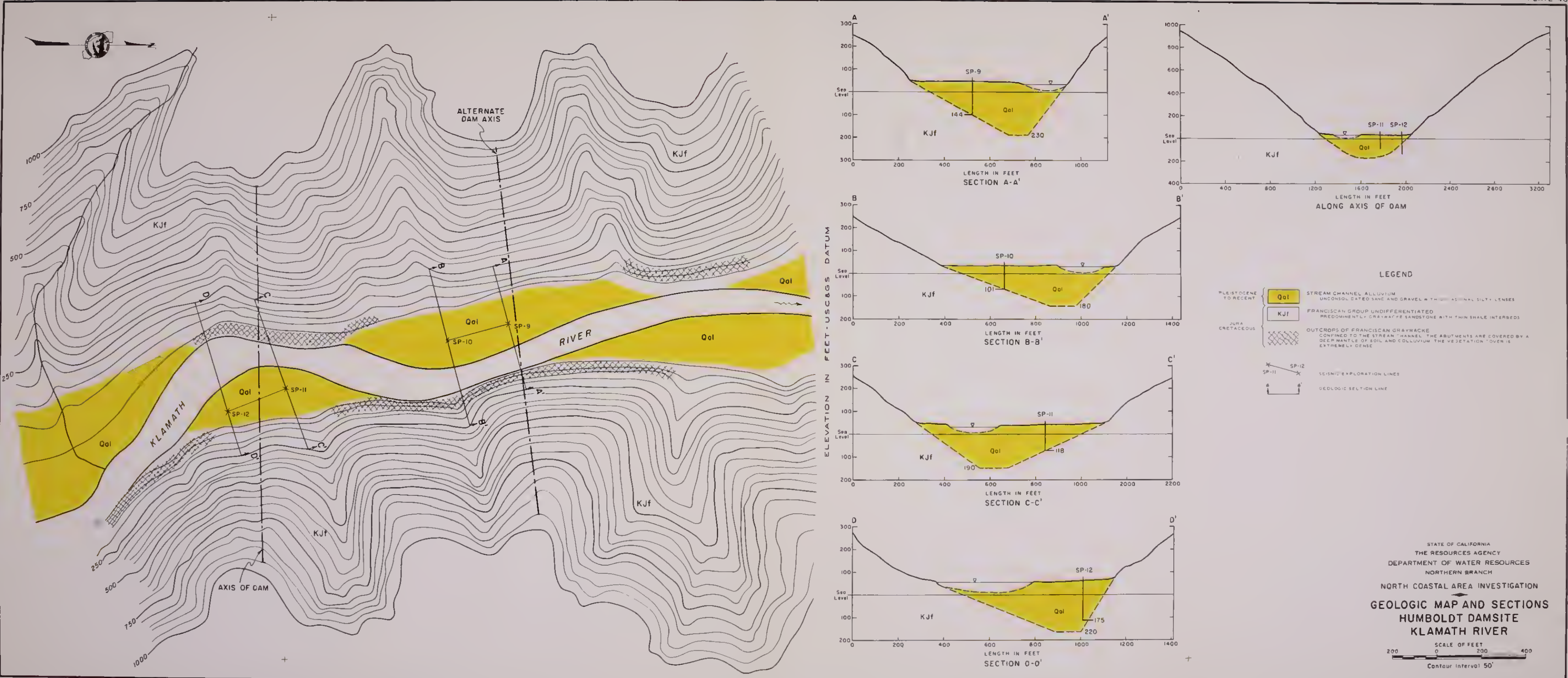
NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS
HUMBOLDT DAMSITE
KLAMATH RIVER

SCALE OF FEET
200 0 200 400

Contour Interval 50'



STATE OF CALIFORNIA
THE RESOURCES AGENCY
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NORTHERN BRANCH

NORTH COASTAL AREA INVESTIGATION

GEOLOGIC MAP AND SECTIONS
HUMBOLDT DAMSITE
KLAMATH RIVER

SCALE OF FEET
200 0 200 400
Contour interval 50'

Dl.